RESEARCH ARTICLE

Assessment of Natural Products as Bio Adsorbents for the Removal of NO$_2$ from Aqueous Solution

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ABSTRACT

The advent of environmental friendly bioadsorbents for removing NO$_2$ from its aqueous solution is discussed in the current paper. Powders of Hibiscus (leaves and flowers), Hibiscus sabdariffa (leaves), Bacopa monnieri (leaves), Amaranthus cruentus (leaves), Syzygiumcumini (leaves), Citrus limetta (peel), Aloe Barbadensis Miller (leaves), Ecliptaprostrata (leaves), and Nelumbo nucifera were used to prepare the adsorbents in the form of powder (seed). To assess their effectiveness in removing NO$_2$ from aqueous solution, adsorption tests using these adsorbents were conducted in batch mode at room temperature. Adsorbents for the elimination of NO$_2$ included Nillumbik nucifera, Hibiscus sabdariffa, Bacopa monnieri, Syzygiumcumini, and Hibiscus leaf showed markedly high adsorptive for NO$_2$ removal. These adsorbents were chosen for further research because of their high efficacy in developing a catalytic tube for reducing air pollution brought on by vehicle exhaust.

Keywords: Bioadsorbents; Adsorption; Environmental; Economical; Batch method; Efficiency; Pollution; Catalytic tube; Vehicular exhaust;

INTRODUCTION

The Global Air Quality Guidelines, issued by WHO in multiple volumes, offer information on the health risks connected to exposure to outdoor air pollution. Guidelines for air quality need to be periodically reviewed and changed when new scientific evidence is produced [1]. Compared to water and sanitation problems the eminence of air pollution in Indian cities is rather a new phenomenon. Industrial and automobile emissions are putting average urban citizens to sickness and health hazards. Industrial civilization is possible only when the huge stock of energy

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stored in the fossil fuels is trapped by mining of fuels like coal and petroleum products. Consumption of these fuels in turn contributes to all types of pollution in the atmosphere.

Owing to the extensive occurrence of both natural and artificial sources, nitrogen dioxide (NO_2) is a common air contaminant. When inhaled at high amounts, it can irritate the respiratory system [2]. Acute exposure of humans to NO_2 at concentrations above about 150ppm (282mg/mi3) causes death, either rapidly due to pulmonary oedema or after a few weeks due to bronchiolitis obliterans with severe fibrosis [3]. NO_2 exposure in confined spaces has resulted in massive harm to humans, including death. By interacting with the immune system, ambient NO_2 exposure may lead to increased risk of respiratory tract infections [4]. Concerns about adverse health effects and also effects on the environment led to implementation of various regulations to decrease the emissions of harmful air pollutants [5].

Urbanization is taking place at the overwhelming pace in India and pressure on natural resources and environmental impacts that is inevitable consequence is leading environmental scientist and managers to address the environmental sustainability. In effects to uplift the underprivileged section of society to a reasonable standard of living, environmental determination in the future/present is inevitable even in the development is done carefully. The trend rural-urban immigration is posing further challenges which is leading to wide spread damage and degradation in recent years. An inclusive urbanization approach is called upon where the waste materials must be recovered for efficient solid waste management to develop a zero waste concept among urban population. In this context of 3R's (Reuse-Reduce-Recycle) the present work uses bio materials for controlling air pollution caused by NO_2. These biomaterials materials were screened for developing a low cost eco-friendly catalytic tube which can be put up for reducing air pollution brought on by vehicle exhaust.

MATERIALS AND METHODS

Condensation, oxidation, dry absorption, or adsorption with or without chemical reaction is the methods typically used to remove or regulate nitrogen dioxide. Adsorption is the strategy employed for the current study. Adsorption approaches are used for non-combustible and low concentration gases. The combustion process does not support nitrogen dioxide, although NO_2 can be managed efficiently by using adsorption techniques.

Selection of Adsorbent
The substances selected are
1. *Nelumbo nucifera*
2. *Hibiscus sabdariffa*
3. *Bacopa monnieri*
4. *Syzygium cumini*
5. Hibiscus leaf and flower
6. *Amaranthus cruentus*
7. *Citrus limetta*
8. *Aloe Barbadensis Miller*
9. *Ecliptaprostrata*

Nelumbo nucifera
The floating-attached plant known as the lotus is a significant and well-liked revenue crop in numerous Asian nations. There are several uses for the lotus plant, including using the stems and rhizomes as fresh vegetables, the seeds as food and medicine, the blooms as religious ornaments, and various sections as cosmetics raw materials.(*Nelumbo nucifera* shows high potential for usage in wastewater treatment removing polluting compounds *and heavy metals.*

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Some thermally stable proteins found in Nelumbo nucifera are useful in protein bioengineering procedures. Lotus seed powder has been researched for reducing NO_2 pollution taking that into account.

Hibiscus sabdariffa

Widely recognised as gongura, which comes in two varieties red-stemmed variety and green stemmed variety. In both sandy and clay soils, it can be grown. For Gongura to grow, loamy soils are ideal. The Hibiscus leaves are high source of Vitamins, fatty acids, carbohydrates, and antioxidants such L-ascorbic acid, -carotene, citric acid, stearic acid, galactose, mucopolysaccharide, polysaccharide, quercetin, anthocyaninspolyphenolic compounds and their derivatives. Hibiscus sabdariffa seeds as coagulant in the waste water treatment along with Carbon as an adsorbent. *From the garden of Hyderabad's St. Ann's College for Women, gongura leaves are picked and dried to prepare an adsorbent.*

Bacopa monnieri: (Bramhi)

Commonly called as Bramhi which is a creeping perennial herb grows in wetlands of eastern and southern India, , Europe, Australia, Africa, Asia, and North and South America. The Roselle variety of *Hibiscus sabdariffa*, L. (Malvaceae) is commonly used. The bacosides, which are triterpenoid saponins of the dammarane type and include jujubogenin or pseudo-jujubogenin moieties as aglycone units, alkaloids are the phytochemicals in *Bacopa monnieri* that have been most thoroughly studied.

Syzygium cumini

An essential ayurvedic plant, *Syzygium cumini* is native to India and is found in the upper Gangetic plains, Bihar, Orissa, and is widely cultivated in Africa.The plant contains β-sitosterol, essential oils, gallic acid, glycosides, cyaniding glycosides, jamboline, tannins, triterpenes, and miricyl alcohol. Gallitannins, monoterpenoid triterpenes, terpenolene, eugenol, and other compounds are present in the leaves that were chosen as an adsorbent.

Hibiscus

Hibiscus rosa-sinensis of Malvaceae family is a glabrous shrub that is extensively grown as an ornamental plant in tropical regions. It comes in a number of variants with different colours of flowers but in medicine, red-flowered plants are preferred. The optimal growing conditions for Hibiscus rosa sinensis are moderate temperatures and a high relative humidity. It does well on loamy, permeable soil that is well drained. *Hibiscus rosa-sinensis* was found to include tannins, anthraquinones, quinines, phenols, flavanoides, alkaloids, terpenoids, saponins, cardiac glycosides, protein, free amino acids, carbohydrates, reducing sugars, mucilage, essential oils, and steroids, as per the phytochemical analysis. The plant's leaves and flowers were chosen for adsorption.

Amaranthus cruentus

Amaranths are a genus of annual or transient perennial plants some of which are found all over the world. Amaranths are some of the earliest vegetables that have existed, globally, as grains, leafy vegetables, dye plants, ornamentals, and weeds, in tropical, subtropical, and temperate climates. The majority of Amaranthus species are summer annual weeds recognized as pigweeds. Major innovations in bioremediation research indicate that using plant-based materials is feasible and has few to no adverse effects. Compared to engineering-based methods, using plants to fix, degrade, and remove pollutants has become a safer, more economical, and complementary green approach since plant tissues operate as routes for the uptake, chelation, and volatilization of pollutants.

Citrus limetta

Commonly called as sweet lime. One of the most widely processed fruits, citrus yields a variety of industrial byproducts. Citrus peels, which make up the majority of citrus "residue," as a low cost adsorbent have many potential uses in removal of dyes and pollutants.

Aloe Barbadensis Miller:

Aloe vera is a succulent plant species that belongs to the genus Aloe and is extensively widespread. In many parts of the world, it is recognized as an exotic species. Evergreen perennial succulent that is native to the Arabian Peninsula

but grows uncontrolled in dry, arid, and semi-tropical environments all over the world. *Aloe vera* leaves include phytochemicals such as anthrones, polymannans, acetylated mannans , anthraquinones like emodin and different lectins that are being investigated for their potential bioactivity. Based on many works on adsorption using aloe vera leaves it was selected for the present work.

Ecliptaprostrata
A medium-sized, branching, annual herb in the sun flower family with a white blossom that is commonly referred to as "Bringraj" can be found worldwide in tropical and subtropical climates widespread across much of the world. The plant has wide applications in medicine as well as environment because of which it has been selected as an adsorbent.

METHOD

Biosorption
A stock solution of 100ppm sodium nitrite is prepared using distilled water. Batch adsorption studies have been carried out by taking 40 ppm of 100ml aqueous solution of NO_2. 1 gm of adsorbent is added to bottles. The initial and final concentration of NO_2 in the solution was determined by using the protocol framed by Yokohama City Research Institute of Environmental Science. The percentage removal of NO_2 is calculated.

RESULTS AND DISCUSSIONS

The materials used are no cost in nature and they are eco-friendly. The adsorption capacity of bioadsorbents for the screening of NO_2 from aqueous solution was assessed by using screening tests. The order of removal efficiency was found to be (Fig:1) *Nelumbo nucifera>Hibiscusssabdarrifa> Bacopa monnieri>S yzygiumncumini> Hibiscus leaf> Amaranthus cruentus> Citrus limetta>Hibiscusflower>Aloe Barbadensis Miller >Ecliptaprostrata.* As percentage removal of adsorbents is ranging between 62-65% they can be successfully used as adsorbents for the removal of NO_2.

CONCLUSIONS

- The adsorbents without any further modification can be successfully used as they given positive results towards removal of NO_2.
- Hibiscus flower and were tested the percentage removal for flowers are less than the leaf which indicates the mechanism of the removal of NO_2 differs from leaf to flower which has to be further investigated.
- A versatile and safe protocol for the removal of NO_2 will be developed for screening of adsorbents.
- The removal of NO_2 molecules is influenced by cellulose, pectin, hemicellulose, surface area distribution, and practical size distribution.
- Batch biosorption studies were identified as a useful rapid screening tool forchecking the potential capacity for removal of NO_2 as good correlations observed in 3 sets of data that was identified by screening with the adsorbents.
- This versatile technique gives insight of biosorption phenomena and insight into selective adsorption performance of leaves, flower, root and different species of same plant family. The performance index can be calculated which gives an insight of mechanism, performance of each part of plant.
- NO_2 from the air and mixture of gases and scale up process evaluations can be carried out which will help in developing a catalytic tube.

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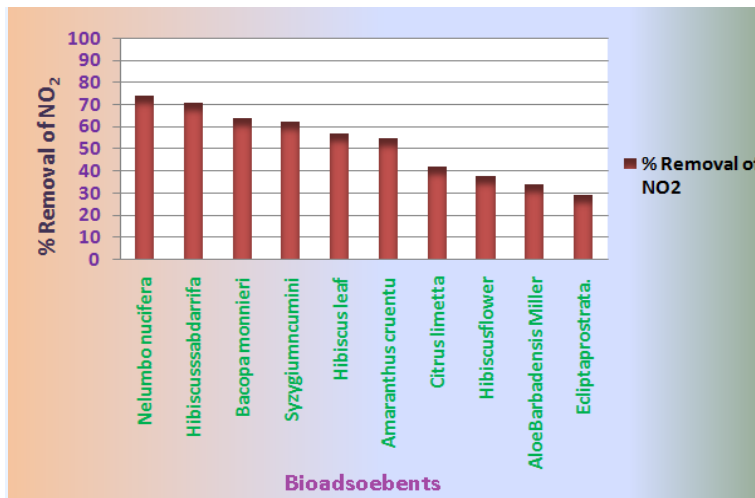
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Fig: 1 % Removal of NO$_2$ with various adsorbents

RESEARCH ARTICLE

Docking Studies of BACE-1 Protein Target with Ginger Components as Novel Lead for the Design of novel anti-Alzheimer's Drug

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ABSTRACT

Alzheimer's disease (AD) research focuses on BACE1, an aspartyl protease that is involved in the uncontrolled creation of amyloid plaques (A), which are characteristic of the disease's pathogenesis. Recent studies on bioactive compounds of Ginger (Zingiber officinale) revealed their role in treating Alzheimer's disease but provided little information on the probable mechanism by which it exerts this anti-Alzheimer activity. In this context, the current study makes use of molecular docking experiments to identify the bonding interactions between the BACE1 protein as target (PDB Id: 4 IVT) and 12 molecules of ginger as ligands (3D structures), utilizing Lamarckian genetic algorithm methods and the AutoDock 4.2 program. The Binding energy values of all 12 ligands were found to be fairly well with a maximum of -8.55K.Cal/mole for the ligand numbered 11 which can be used as a lead molecule for designing Anti Alzheimer's agents.

Keywords: Alzheimer's; BACE1; bioactive; Ginger; molecular docking; target; ligands; AutoDock 4.2; Lamarckian genetic algorithm; Binding energy.

INTRODUCTION

Alzheimer's disease is a progressive neurologic disorder that causes the brain to shrink and brain cells to die. The beta-amyloid protein accumulates extracellularly as a symptom of Alzheimer's disease (AD) (Abeta). Abeta is a portion of the amyloid precursor protein, a much larger precursor protein (APP)[1]. Alzheimer's disease (AD) research focuses on BACE1, an aspartyl protease that is involved in the aberrant creation of amyloid plaques (A), which are the hallmark of the disease's pathogenesis[2].An aspartic protease called BACE1 is involved in the first stage of the process, resulting in the formation and deposition of amyloid- β peptide (Aβ). The transmembrane aspartyl protease known as BACE1 is responsible for cleaving APP at the β- site. Aβ peptide is produced and

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released in the brain as a result of the successive proteolytic cleavage of APP by BACE1 and β-secretase[3]. As a result, major therapeutic targets for AD-modifying intervention are now being examined including amyloidogenic secretases. According to several studies, BACE1 inhibitors have a great deal of promise as a potential method for lowering AD brain concentrations and halting the course of AD[4]. Numerous studies were undertaken to define the properties of β-secretase activity. While β -secretase activity was detected in the majority of body tissues, maximal activity was found in neural tissue and neuronal cell lines. Interestingly, astrocytes exhibited less β-secretase activity than neurons[5]. Neurons are responsible for the major portion of BACE1 and Aβ expression in the brain under normal conditions, and this is also likely to be true during AD. However, evidence is mounting that glia, and astrocytes, in particular, may produce significant levels of BACE1 and Aβ, especially during inflammation.

Ginger has powerful antioxidant and anti-inflammatory properties, and some of the pungent components found in ginger and other zingiberaceous plants have been shown to prevent cancer in experimental carcinogenesis[6]. According to folkloric medicine, ginger has been used to manage or treat Alzheimer's disease There is little research validating the potential of ginger for neuroprotection against Aβ induced toxicity in cell culture studies[7] and reversal of behavioral dysfunction in rats[8]. These observations prompted us to identify the molecular targets of action of dry ginger contributing to its anti-Alzheimer effects. Ginger extract can prevent the increase in cholesterol levels following intake of a cholesterol-rich diet by rats and rabbits thus protecting against atherosclerosis, therefore, ginger acts as a hypolipidemic factor. Ginger also inhibits platelet aggregation. It has anti-oxidative properties and scavenges superoxide anion and hydroxyl radicals due to its high content of gingerol which is a polyphenolic compound. Ginger also has anti-inflammatory properties due to the inhibition of prostaglandin and leukotriene biosynthesis owing to its content of Gingerols and diarylhepatanoids[9]. Thus, this method is being used in the current investigation to examine the binding relationships between active ginger components and several anti-Alzheimer medication targets. Additionally, to assist in lead optimization, this will be crucial in identifying the anti-processes of Alzheimer's and the interactions of ginger components with several targets[10].

MATERIALS & METHODS

Preparation of the protein receptor
The protein-ligand crystal structure of the AD-associated target was used for the docking calculations. the target BACE-1 was downloaded from the Research Collaboratory for Structural bioinformatics (RCSB) Protein data bank (PDB Number: 4 IVT). The water molecules are removed and the missed hydrogen atoms are added to the crystal structure of the target using PyMol 2.5.4 software. This was used for docking studies.

Preparation of ligand
From the literature survey,[11]12 different ginger components(Figure 1) acting on various nervous systems were retrieved and their activity was proven in vitro or in vivo. Using ChemDraw 8.0 software the 12 structures were drawn and converted to their three Dimensional structure using Chem3D. Finally, the structures are converted to .pdb format for further docking studies.

Docking Simulation
The Auto Dock 4.2 (The Scripps Research Institute, La Jolla, CA, USA) software was used to employ the Lamarckian genetic algorithm to implement the docking simulations.[12] the standard docking procedure was used for a rigid protein and a flexible ligand whose torsion angles were identified (for ten independent runs per ligand). A grid in x,y, and z directions with 56,60, and 50 points respectively, and with a grid spacing of 0.375 A⁰. The default settings were used for all other parameters.

RESULTS AND DISCUSSIONS

The different components of ginger were docked. The docking results of each structure and their binding energies

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are shown in Table 1.

Compound 1: In these 23 nonpolar hydrogens found, 6 aromatic carbons and 10 rotatable bonds were detected. It shows binding energy of -6.27 KCal/ mole and total energy of -1.65 KCal/mole. H-bonding with THR-232 and Hydrophobic interactions THR-231, GLY-230, and PHE-108.The Doc pose is shown in Figure 3.

Compound 2: In this 21 non-polar hydrogens were found, and 6 aromatic carbons and 10 rotatable bonds were detected. It shows binding energy of -6.34 KCal/ mole and a total energy of -1.64 KCal/mole. H-bonding with PHE-108 and Hydrophobic interactions LYS-107, TYR-71, and GLN-73.The Doc pose is shown in Figure 4.

Compound 3: In these 13 non-polar hydrogens found, 6 aromatic carbons and 5 rotatable bonds were detected. It is showing binding energy of -5.26KCal/ mole and total energy of -1.1 KCal/mole. H-bonding with LYS-107 and Hydrophobic interactions THR-231, TYR-71, and GLN-73.The Doc pose is shown in Figure 5.

Compound 4: In these 24 nonpolar hydrogens found, 6 aromatic carbons and 12 rotatable bonds were detected. It shows binding energy of -5.65KCal/ mole and total energy of -2.18 KCal/mole. H-bonding with - ASP-32, TYR-71, LYS-107 and Hydrophobic interactions THR-72 and GLN-73.The Doc pose is shown in Figure 6.

Compound 5: In these 32 nonpolar hydrogens found, 6 aromatic carbons and 16 rotatable bonds were detected. It is showing binding energy of -6.03 KCal/ mole and a total energy of -1.94 KCal/mole. H-bonding with ASP-228, PHE-108 and Hydrophobic interactions GLY-230, GLY-74 and GLN-73.The Doc pose is shown in Figure 7.

Compound 6: In these 22 nonpolar hydrogens found, 12 aromatic carbons and 12 rotatable bonds were detected. It shows binding energy of -6.62 KCal/ mole and total energy of -2.59 KCal/mole. H-bonding with TYR-198, THR-231, PHE-108 and Hydrophobic interactions GLY-230, GLY-74 and GLN-73.The Doc pose is shown in Figure 8.

Compound 7: In these 22 nonpolar hydrogens found, 12 aromatic carbons and 11 rotatable bonds were detected. It is showing binding energy of -7.54 KCal/ mole and total energy of -2.25 KCal/mole. H-bonding with ILE-126, PHE-108 and Hydrophobic interactions GLY-230, TYR-231 and GLN-73.The Doc pose is shown in Figure 9.

Compound 8: In these 29 nonpolar hydrogens found, 12 aromatic carbons and 17 rotatable bonds were detected. It is showing binding energy of -4.92 KCal/ mole and total energy of -3.95 KCal/mole. H-bonding with SER-13, THR-231, PHE-108, IYS-107 and Hydrophobic interactions GLY-230, TYR-231 and GLN-73.The Doc pose is shown in Figure 10.

Compound 9: In these 24 nonpolar hydrogens found, 12 aromatic carbons and 14 rotatable bonds were detected. It is showing binding energy of -6.16 KCal/ mole and a total energy of -2.33 KCal/mole. H-bonding with ASP-228,ASP-32, ARG-128, PHE108 and Hydrophobic interactions GLY-74, TYR-71 and GLN-73.The Doc pose is shown in Figure 11.

Compound 10: In these 22 nonpolar hydrogens found, 12 aromatic carbons and 14 rotatable bonds were detected. It is showing binding energy of -7.02 KCal/ mole and a total energy of -2.88 KCal/mole. H-bonding with LYS-107, ASP-32, SER-35, PRO-70, PHE-108 and Hydrophobic interactions GLY-74, TYR-71 and GLN-73.The Doc pose is shown in Figure 12.

Compound 11: In these 22 nonpolar hydrogens found, 12 aromatic carbons and 10 rotatable bonds were detected. It is showing binding energy of -8.55 KCal/ mole and total energy of -2.76 KCal/mole. H-bonding with GLN-73, THY-72(2 BONDS), ASP-32, PHE-108   and Hydrophobic interactions GLY-34, THR-231 and LYS-107. The Doc pose is shown in Figure 13.

Compound 12: In these 23 nonpolar hydrogens found, 12 aromatic carbons and 9 rotatable bonds were detected. It is showing binding energy of -7.98 KCal/ mole and total energy of -2.02 KCal/mole. H-bonding with H-BONDING: PRO-70, ARG-128, GLY-34 and Hydrophobic interactions GLY-34, TYR-71 and GLN-73.The Doc pose is shown in Figure 14.

CONCLUSION

The selected components of ginger are docked with the BACE1 target. all the structures are showing interactions with the target. of all those compounds 11 show the highest binding energy i.e -8.55 KCal/ mole. The compound 11 is bonded with 5 amino acids with Hydrophilic interactions. from the above data we can tell that Ginger components may act as better Anti Alzheimer's agents. Upon usage of Natural products, ginger may cure Alzheimer's disease.

ACKNOWLEDGMENT

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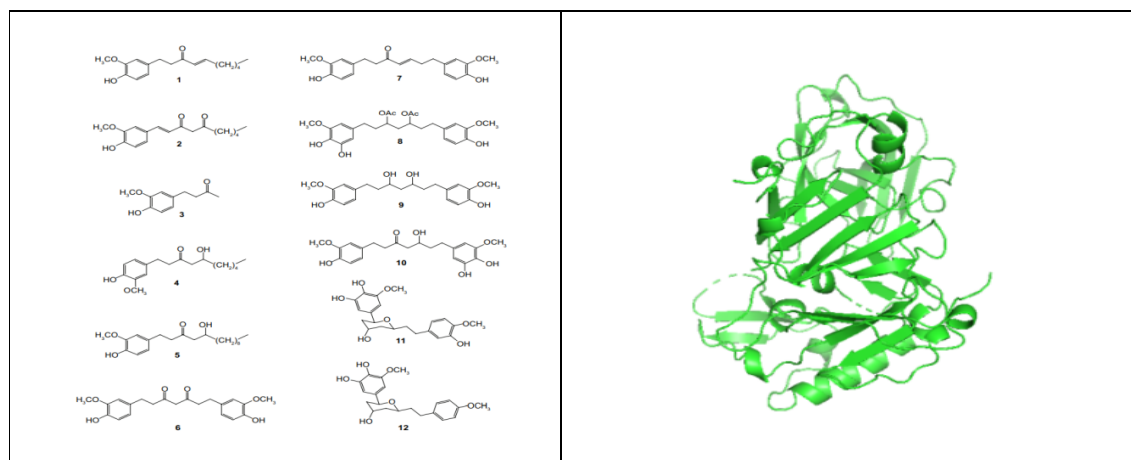
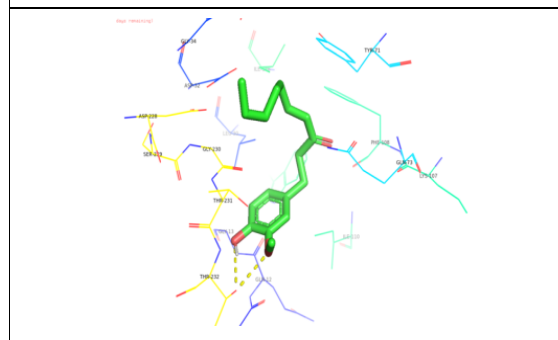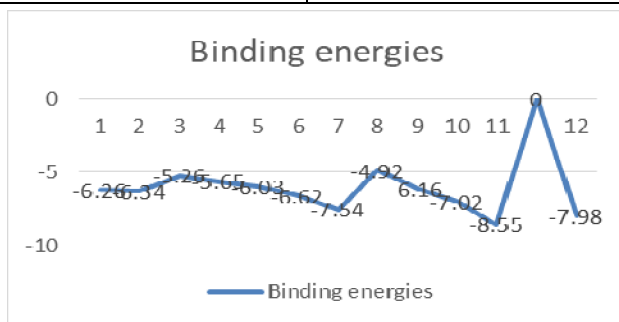**Srilaxmi *et al*.,**

Figure 1: Active components of ginger

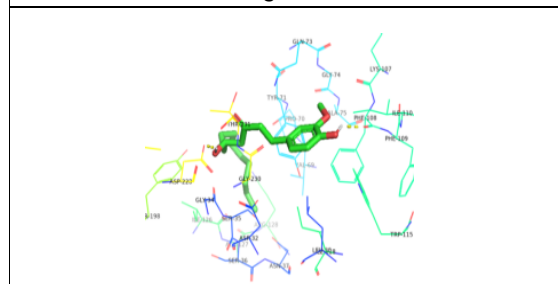Figure 2: Chain A of BACE1 target

Figure 3
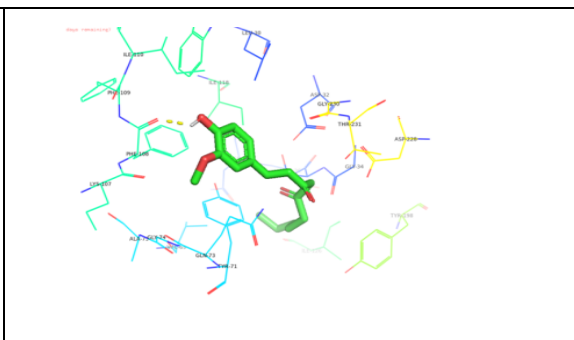
Figure 4

Figure 5

Figure 6

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Figure 7

Figure 8

Figure 9

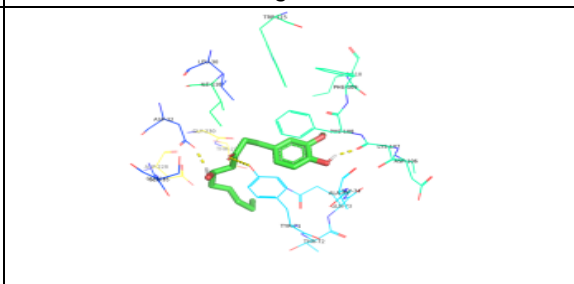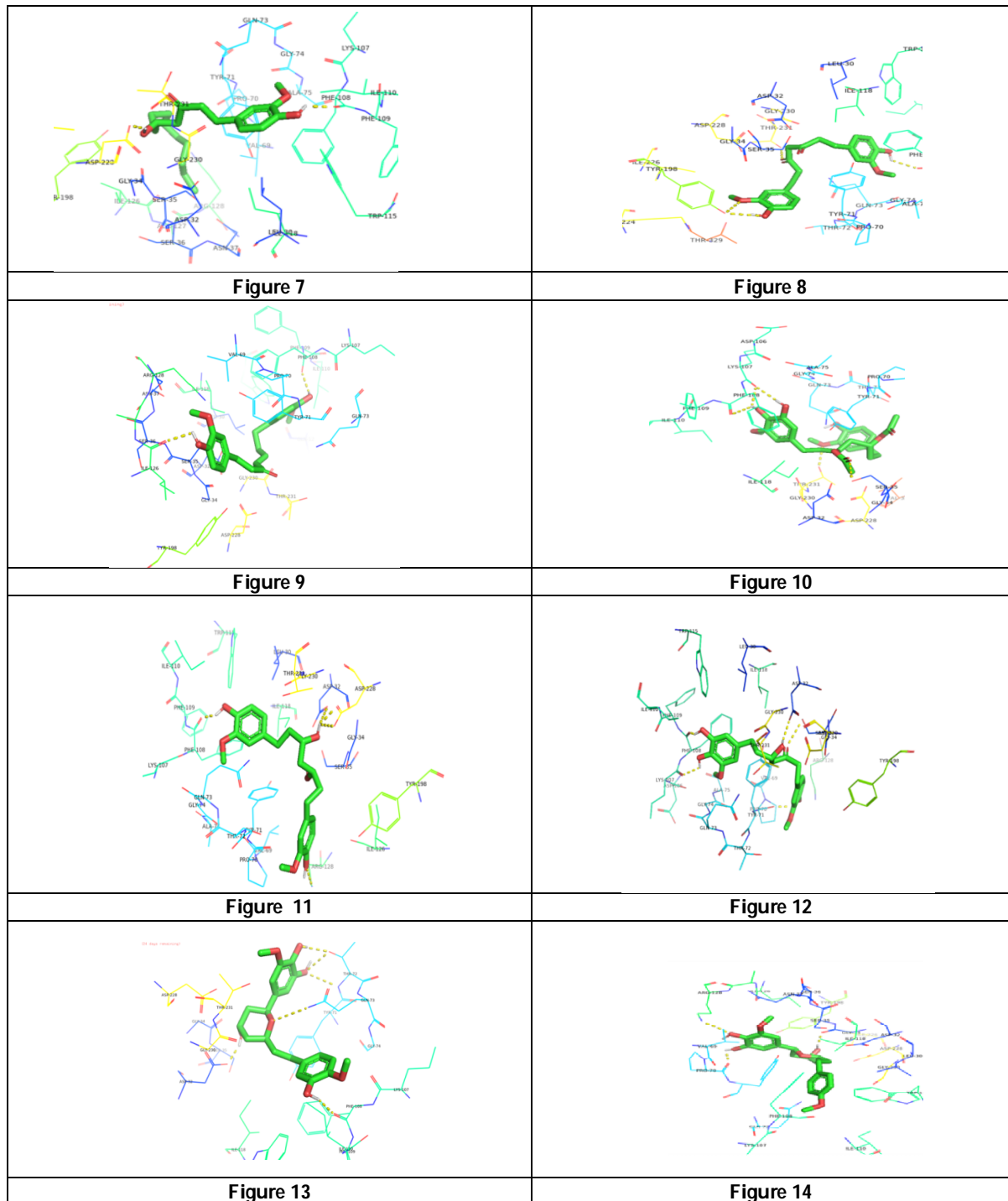
Figure 10

Figure 11

Figure 12

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Figure 14

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ECO-FRIENDLY SYNTHESIS AND CHARACTERIZATION OF MONO, BIMETALLIC AND NON-METAL DOPED SNO$_2$: PHOTODEGRADATION OF DYE AND ITS ANTI-MICROBIAL ACTIVITY

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ABSTRACT

This study shows how green synthesis techniques using Aloe vera gel may produce pure and Zn-doped tin oxide nanoparticles. The group also created Zn-doped SnO$_2$ nanoparticles with changes for silver and nitrogen using a Co-precipitation method. Several analytical methods, including UV-visible diffuse reflectance spectra (UV-vis-DRS). The optical characteristics, phase structures, and morphologies of the produced nanoparticles were evaluated using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray photoelectron spectroscopy (XPS). When compared to SnO$_2$, the modified photocatalysts (Zn-Ag/ SnO$_2$ and Zn-N/ SnO$_2$) showed a shift in the visible spectrum toward longer wavelengths. The photodegradation of Methylene blue was observed to gauge the photocatalytic performance. The findings revealed that Zn-N/SnO2 exhibited superior photocatalytic efficiency compared to Zn-Ag/SnO$_2$, Zn/SnO2, and SnO$_2$. This improved performance can be attributed to the efficient separation of electron-hole pairs enabled by surface modification. Furthermore, the antimicrobial properties of the nanocomposites were examined.

Keywords: Green Synthesis, Nanocomposites, Photocatalysis, Methylene Blue, Antimicrobial Activity.

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INTRODUCTION

Water contamination is escalating in severity as industrialization progresses so quickly. According to the World Health Organization (WHO), humans cannot safely consume more than 99% of the world's water supplies.[1,2] One of the biggest pollutants that endangers the environment and all earthly life is dyes. The intricate design of these makes it difficult to remove or degrade these big molecules from effluents because dyes make them more stable. The focus of the recent study has been the removal of harmful wastewater organic contaminants by physical, chemical, and biological processes that have some restrictions.[3] Because of the inherent stability in their chemical composition, the majority of these compounds cannot be efficiently eliminated using traditional techniques like coagulation, sedimentation, filtration, absorption, and membrane technologies.[4] Hence, it is of utmost importance to establish a precise technology for the degradation of aqueous dyes, especially given the worldwide shortage of clean drinking water. SnO$_2$ nanoparticles can be synthesized using methods including chemical precipitation, auto-combustion, thermal evaporation, solvothermal processes, spray pyrolysis, hydrothermal methods, and sol-gel techniques.[5] The hydrothermal synthesis approach offers several benefits, including its environmentally friendly nature, cost-effectiveness, and high level of efficiency. Moreover, it enables control over surface characteristics, particle dimensions, compositions, and morphologies.[6,7] Being among the most significant semiconductor oxides, tin oxide (SnO$_2$) has been a subject of investigation for its potential as a photocatalyst. The findings demonstrate that SnO$_2$ has displayed photoactivity in the context of degrading dyes and other organic substances.[8] Tin oxide nanoparticles doped with zinc have found applications in various fields such as antibacterial agents, cosmetics, photovoltaic devices, catalysts, solar cells, transparent electrodes, and gas sensors.[9-13] The practical applications of semiconductor nanoparticles' bactericidal activity under visible light are of great significance. Historically, much of the research has focused on utilizing ultraviolet light, with only a limited number of recent investigations delving into bacterial photoinactivation through visible light exposure. These studies

encompass a range of semiconductor-based systems, including composites[14]doped with transition metals,[15] noble metals[16], and organic/inorganic combinations.[17] In the domain of heterogeneous catalysis, various methods are available to engineer and improve material surfaces. In our research, we selected the co-precipitation method, recognized for its simplicity and high efficacy in producing supported catalysts. With this method, a specific quantity of catalyst precursor is introduced onto the surface of the material via a variety of techniques, such as altering the surface's hydroxyl (OH) groups or using adsorption. This method reveals that it is the easiest and most advanced method for developing supported catalysts.

EXPERIMENTAL

Material and Methods
The analytical grade of all compounds was purchased. Without further purification, methylene blue, sodium hydroxide (NaOH), zinc acetate, tin chloride ($SnCl_2$) (SD FINE Chemicals), and Silver nitrate were all used.

Analysis of Photo Catalytic Activity
250 ml of Methylene blue dye and 0.50 g of catalyst were combined in a 500 ml cylindrical quartz glass reactor. To reach adsorption-desorption equilibrium, dark adsorption experiments were carried out for 30 min after the photodegradation tests were conducted under visible light for 300 min. Every 30 minutes, samples were taken and examined with a UV-vis spectrophotometer up to 800 nm.

General Procedure
Green Synthesis of SnO_2
In a typical procedure, Tin oxide (SnO_2) was synthesized using Tin chloride as the precursor. Initially, an appropriate quantity of Tin chloride was dissolved in a minimal volume of an environmentally friendly solvent, Aloe vera gel. To this Tin chloride solution, 3 N NaOH was cautiously added drop by drop while continuously agitating the mixture using a magnetic stirrer. Up till a white precipitate was produced, this procedure proceeded. A suction pump was used to separate the resulting white precipitate, and contaminants were then removed by washing it several times with distilled water. The dried precipitate was then baked at a temperature that was gradually raised over about 24 hours, from 150 to 180^0C. The dried material was identified as cerium hydroxide. This cerium hydroxide was subjected to calcination at $600\ ^0C$ for approximately 6 hours in a muffle furnace, resulting in the formation of a finely powdered pale white SnO_2 material.

Green Synthesis Zn Doped SnO_2 (Z-Sn)
Tin oxide (SnO_2) was synthesized using Tin chloride as the starting material. Initially, 4.8 grams of Tin chloride were dissolved in 50 ml of an environmentally friendly solvent, Aloe Vera gel. To this Tin chloride solution, 0.45 grams of Zinc acetate were added. Subsequently, 3 N NaOH was carefully introduced drop by drop while maintaining continuous stirring through a magnetic stirrer. Then, 3 N NaOH was gradually added while stirring was maintained continuously. This process continued until a white precipitate was generated. A suction pump was used to separate the resulting white precipitate, and any impurities were then eliminated by repeatedly washing it in double-distilled water. The washed precipitate was then dried by gradually increasing the temperature from 150 to $180\ ^0C$ over a span of approximately 24 hours. The resulting dried white precipitate was subjected to calcination at $600\ ^0C$ for around 6 hours using a muffle furnace. This process yielded a finely powdered white material, specifically a $Zn-SnO_2$ composite.

Green Synthesis of Zn-Ag Doped SnO_2 (A-Z-Sn)
Tin oxide (SnO_2) was synthesized using Tin chloride as a precursor. The procedure began with the dissolution of 4.8 grams of Tin chloride in 50 ml of an environmentally friendly solvent, Aloe Vera gel. To this solution of Tin chloride, 0.435 grams of Zinc acetate and 0.0725 grams of silver nitrate were added. A magnetic stirrer was then used to continuously mix while adding 3 N NaOH drop by drop after that. A white precipitate eventually formed as a result of this. Through the use of a suction pump, the resulting white precipitate was separated from the contaminants by being put through several cycles of washing with double-distilled water. Subsequently, the washed precipitate was dried by raising the temperature from 150 to $180\ ^0C$ over approximately 24 h. The dried white precipitate was then put

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through a 6-hour calcination process in a muffle furnace at 600 ^{0}C. This method produced a white substance that was finely powdered and comprised a composite of Ag-Zn-SnO$_2$ (A-Z-Sn).

Green Synthesis Zn-SnO$_{2-x}$N$_x$ (N-Z-Sn)
Tin oxide (SnO$_2$) was synthesized from Tin chloride in the following manner: Initially, 4.8 grams of Tin chloride were dissolved in 50 ml of an environmentally friendly solvent, Aloe Vera gel. To this solution of Tin chloride, 0.45 grams of Zinc acetate and 1M urea were added. After that, 3 N NaOH was gradually added while being continuously stirred with a magnetic stirrer until a white precipitate was formed. Using a suction pump, the resulting white precipitate was removed from any remaining contaminants before being repeatedly washed with double-distilled water. Afterward, the washed precipitate was dried by gradually raising the temperature from 150 to 180 ^{0}C over a span of around 24 hours. The dried white precipitate was then subjected to calcination at 600 ^{0}C for approximately 6 hours using a muffle furnace. This process yielded a finely powdered white material, specifically a composite containing ZnO and Nitrogen-doped in SnO$_2$, referred to as Zn-SnO$_{2-x}$N$_x$ (N-Z-Sn).

Detection Method
Powdered X-ray diffraction investigations with Cu-K radiation (Kα = 0.1540) were performed using a Rigaku Smart X-ray diffractometer. The scans were carried out in the range of 2**θ** from 10° to 80° with a step size of 0.02° and a scan step length of 0.15 seconds. Using a SHIMADZU UV-2600 spectrophotometer, UV-visible absorption spectra between 200 and 800 nm were collected. For the measurements, a quartz cell with a 1.0 cm path length was employed. The catalysts were examined using a Perkin-Elmer infrared model for FT-IR spectroscopy. The wavelength range that was covered was 400 to 4000 cm^{-1}. Using a Shimadzu 3140 X-ray photoelectron spectrometer, X-ray photoelectron spectroscopic (XPS) pictures were taken. The energy employed for excitation was 1253.6 eV (Mg Ka), with the energy set at 80 eV. SEM with energy-dispersive X-ray spectroscopy (EDX) capabilities was used to evaluate surface composition and morphology (BITS, Goa Campus). The Quanta FEG 250 SEM apparatus was employed, and it ran at a 20 kV acceleration voltage. A Lab Ram HR Evolution Raman Spectrometer from Horiba Scientific that has a CCD detector was used to produce Raman spectra at ambient temperature. A helium-neon (HeNe) laser's 633 nm excitation line was used to capture the spectra, which have a range of 50–2000 cm^{-1} and a spectral resolution of 2 cm^{-1}. Lastly, the produced nanomaterials' antibacterial activity was studied.

RESULTS AND DISCUSSION
Figure-1 displays the XRD pattern of the tin oxide nanoparticles as they were synthesized. With reference to SnO$_2$'s tetragonal rutile structure (JCPDS card No. 41-1445, a = 4.738 Å and c = 3.187 Å), all of the peaks in Fig.-1 may be accurately cataloged. The products were extremely pure because no distinctive peaks of contaminants, including surfactant or other tin oxides, were seen. Peaks (110) and (101) have the highest relative intensities. In oxides with rutile structure[18,19] the low index (110) face has the lowest surface energy and is the most thermodynamically stable bulk termination.[20] The seven distinctive (100), (002), (101), (102), (110), (103), and (112) crystal planes of the conventional hexagonal wurtzite ZnO phase (JCPDS No. 76–0704) are represented by the diffraction peaks of pure ZnO.
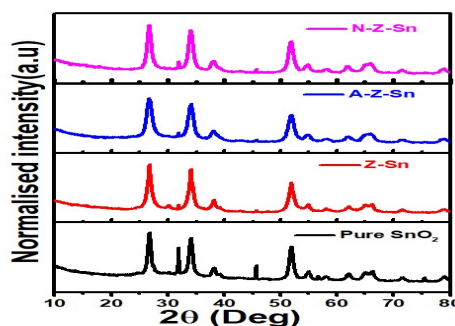

Fig.-1: Powder XRD Patterns of Pure SnO$_2$, as Produced Zn Doped SnO$_2$, Zn-Ag Doped SnO$_2$, and Zn-N Doped SnO$_2$ are Shown in (a), (b), and (c), Respectively

There are no more random peaks visible, demonstrating the sample's excellent crystallization and great purity. A tetragonal rutile structure was revealed by the diffraction pattern, with the maximum intensities found in the (110), (101), and (211) planes, with 2θ values of 26.24º, 33.25º, and 51.8º, respectively.[21] Moreover, the diffraction peaks demonstrate that no extra crystalline phase was produced by the Ag doping effect.[22] The SnO_2 crystal structure was not appreciably altered by the nitrogen doping.[23]

FTIR
By analyzing the infrared transmittance spectra of the generated Zn-SnO2 nanoparticles, the vibrational state of the metal ions and functional groups in the materials are revealed. Figure-2a displays the obtained infrared spectra. The peak at 530 cm^{-1} is indicative of the Sn–O bond's symmetric vibration mode .[24]

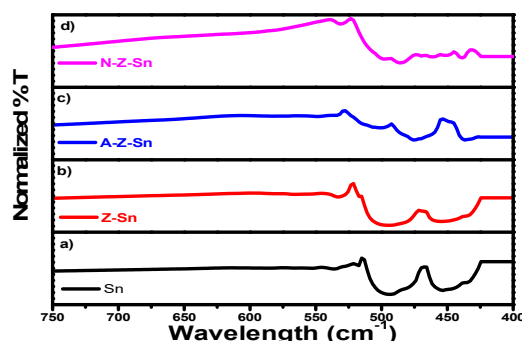Fig.-2a: FTIR Spectra of (a) Pure SnO_2, (b) Zn-SnO_2, (c) Zn-Ag-SnO_2, (d) Zn-N-SnO_2 Materials

Raman Spectra
One method for examining rotational, vibrational, and other low-frequency modes in a system is Raman spectroscopy. In the context of tin oxide (SnO_2), Raman spectroscopy can provide information about its crystal structure, lattice vibrations, and bonding properties. However, I can't provide real-time or up-to-date data, but I can give you some general information about the characteristic Raman values for tin oxide. Tin oxide (SnO_2) typically exhibits Raman peaks associated with its crystal lattice vibrations. The Raman spectrum of SnO_2 is influenced by its crystal structure, which is often rutile-type tetragonal. Stretching of oxygen atoms in the SnO_2 lattice. Raman Shifts are ~632 cm^{-1}, 466 cm^{-1}, 540 cm^{-1}. Because of zinc doped to the tin oxide the Raman peak at 632 cm^{-1} is reduced and the peaks at 575 cm^{-1}, and 439 cm^{-1} are observed these are related to zinc.[25]
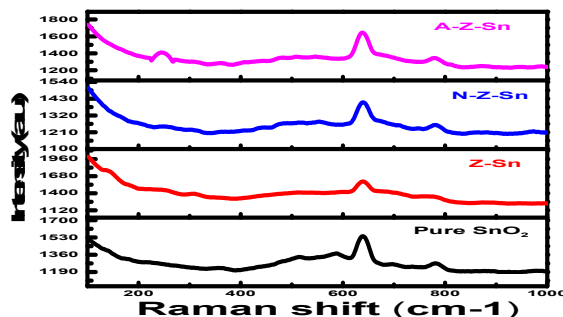

Fig.-3a: Raman Spectra of (a) Pure SnO_2, (b) Zn-SnO_2, (c) Zn-Ag-SnO_2, (d) Zn-N-SnO_2 Materials

X-ray Photoelectron Spectroscopy (XPS)
X-ray Photoelectron Spectroscopy (XPS) is a technique employed to analyze the chemical makeup and electronic configurations of materials by measuring the energies of photoelectrons released from the surface of a sample. In the context of pure SnO_2, Z-Sn, A-Z-Sn, and N-Z-Sn materials survey report as shown in Fig.-4a. The pure SnO_2 showed peaks at 486.63 and 495.07 eV for Sn $3d_{5/2}$ and $3d_{3/2}$ respectively[26], whereas O (1s) peak at 530.64 eV. In the case of Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposites slightly shifted Sn (3d) and O (1s) peaks. This indicated that Zn and Ag metal ions doped into SnO_2 nanoparticles as given in Table-1. From Fig.-4e gives information on Ag metal and N non-metal atoms also doped in SnO_2 nanoparticles.
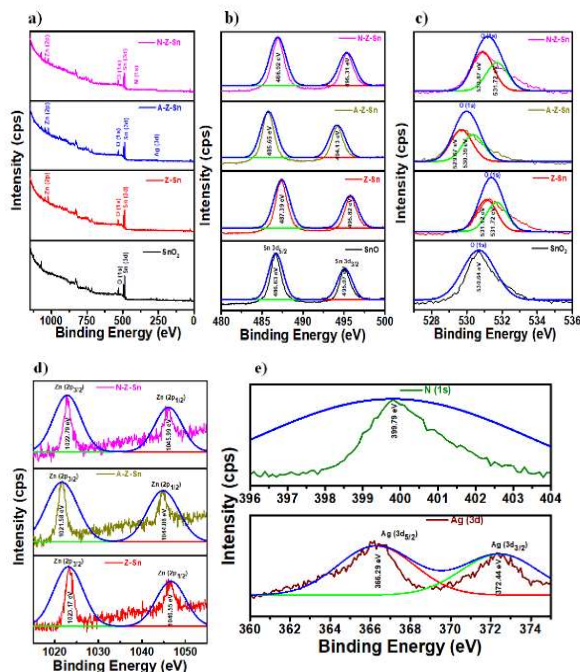
Fig.-4: XPS Spectrum of (a) Survey (b) Sn (3d), (c) O (1s), (d) Zn (2p), and (e) N (1s) and Ag (3d) of all the Materials

Table-1: XPS Data of Pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn Materials

Material	Sn (3d$_{5/2}$) (eV)	Sn (3d$_{3/2}$) (eV)	O (1s) (eV)	Zn (2p$_{3/2}$) (eV)	Zn (2p$_{1/2}$) (eV)	Ag (eV)	N (eV)
Pure SnO$_2$	486.63	495.07	530.64	--	--	--	--
Z-Sn	487.39	495.83	531.12 (Sn-*O*) 531.72 (Zn-*O*)	1023.17	1046.55	--	--
A-Z-Sn	485.65	494.13	529.67 (Ag-*O*-Sn) 530.39 (Zn-*O*)	1021.58	1044.86	366.29 (3d$_{5/2}$) 372.44 (3d$_{3/2}$)	--
N-Z-Sn	486.92	495.31	530.87 (Sn-*O*) 531.72 (Zn-*O*)	1022.79	1045.99	--	399.79

SEM-EDX

Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) elemental analysis are applied for the assessment of surface characteristics and the elemental composition of catalysts, specifically pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn, which have been produced. The EDX spectrum and SEM pictures of pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposite materials. are shown in Fig.-5. Pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn, and significantly irregular-shaped lumps with agglomeration can all be seen in the FESEM pictures. According to EDX analysis, pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn, each demonstrate the elements of Sn, Zn, Ag, N, and O in their respective stoichiometric ratios. Table-2 predicts this percentage of weight for each constituent. Similar to this, the EDX spectrum of pure SnO$_2$, Z-Sn, A-Z-Sn, and N-Z-Sn and the weight percent of the materials in the produced catalyst are reported.

Photodegradation of Methylene Blue

Photodegradation of methylene blue (MB) is one of the best ways to establish the photocatalytic properties of the new photocatalysts due to the most frequently used dyeing system in the textile industry.

Therefore, MB degradation is still a challenging task in the area of the organic pollutants mineralization process. Organic dyes degrade in two different ways when semiconductor oxides are present: first, they transform into stable, non-toxic compounds; second, they turn into carbon dioxide and char.[27]
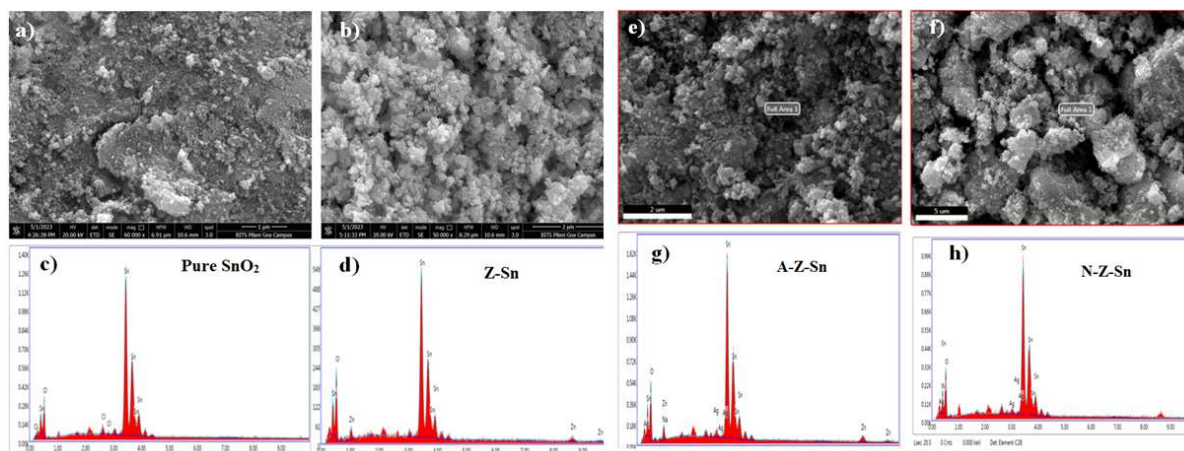

Fig.-5: FESEM Images of a) Pure SnO_2, b) Z-Sn, e) A-Z-Sn, f) N-Z-Sn and EDX of c) Pure SnO_2, d) Z-Sn, g) A-Z-Sn, h) N-Z-Sn Nanomaterials

Decolourization of MB by visible light only, Pure SnO_2, Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposites were used as catalysts for decolorization of MB. Degradation of the MB process was done in (i) only MB in dark and light (ii) MB and catalyst in light and dark (iii) MB, catalyst, and tert-butanol in the dark and light were carried out, and the MB degradation is shown in Fig.-6.
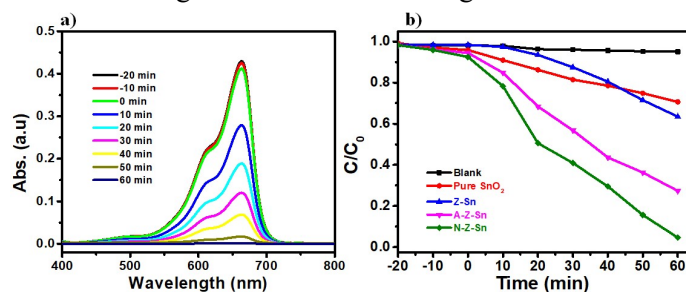

Fig.-6: Photodegradation Image of MB Concerning Photocatalyst

Without any catalyst, the degradation of MB (40 ppm solution) was very low under visible light irradiation. In the presence of visible light radiation, the degradation of MB almost completes within the time after 60 min with visible light irradiation. The degradation of MB was noticeably rapid, with significant degradation observed after 60 minutes of visible light irradiation in the presence of a catalyst, indicating that photolysis was highly efficient for MB degradation. In contrast, when the solution was treated with the catalyst alone in the absence of light, only a minor 2% reduction in color was observed. The visible light process proved to be highly effective in achieving excellent decolorization efficiency. When pure SnO_2, Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposites were employed as catalysts in the dark, the degradation efficiency after 20 minutes reached up to 20%. However, when the reaction took place under visible light conditions, employing SnO2, Z-Sn, A-Z-Sn, and N-Z-Sn systems as catalysts, the highest decolorization efficiency rates were achieved, with approximately 27%, 48%, 74%, and 98% color removal, respectively. These results demonstrate that the degradation rate can be significantly accelerated through the use of visible light radiation. All the samples are found to exhibit photocatalytic activity for MB degradation. Figure-6 shows the photocatalytic activity of pure SnO_2, Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposites The decolorization of MB using N-Z-Sn surpasses that of pure SnO2, Z-Sn, and A-Z-Sn. Specifically, pure SnO2, Z-Sn, A-Z-Sn, and N-Z-Sn nanocomposites can degrade MB by approximately 21%, 39%, 59%, and 85%, respectively, within the initial 50 minutes of the reaction. Subsequently, the

degradation rate becomes notably slower. In the case of pure SnO_2, the degradation of MB reaches around 27% within 60 minutes. A substance's photo activity is determined by several variables, including its surface structure, degree of crystallinity, surface area, structure, pollutant adsorption capacity, band gap energy, and rate of hole and electron recombination. Moreover, it was noted that lanthanides had a positive effect on the photoactivity of nanocrystalline semiconductor photocatalysts.[28]

The improved degradation under visible light exposure can be attributed to the following factors:(i) The lower bandgap (Eg) values of A-Z-Sn and N-Z-Sn materials, (ii) The transitions of 4d electrons of Ag ions and the higher basicity of nitrogen (N) compared to oxygen. This enhances the optical adsorption properties of the catalysts and promotes the separation of photogenerated electron-hole pairs. (iii) Additionally, the red shift of the optical absorption edge of N-Z-Sn, induced by the doping of N^{3-} ions, contributes to the enhancement of the photocatalytic activity of Z-Sn under visible light.

Antibacterial Activity
Bacterial Strains
The Gram-positive bacterial strain, Staphylococcus aureus (ATCC 25923), and the Gram-negative bacterial strain, Escherichia coli (ATCC 25922), employed in the research were procured from the American Type Culture Collection (ATCC).[29]

Media Preparation for Anti-Bacterial Activity
(A) Nutrient Agar Media
We obtained Nutrient Agar commercially and then measured 28.0 grams of the powder, which we dissolved in 1000 ml of distilled water, ensuring thorough mixing. Subsequently, the dissolved Nutrient Agar was sterilized in an autoclave at 121°C for 15 minutes. This sterilized medium was then utilized for the preparation of plates to investigate the antibacterial activity.

(B) Nutrient Broth
We obtained Nutrient Broth commercially and measured 1.3 grams of the powder, which we dissolved in 100 ml of distilled water, ensuring thorough mixing. Subsequently, the dissolved Nutrient Broth was sterilized in an autoclave at 121°C for 15 minutes. This sterilized broth was then utilized for the preparation of inoculum.

(C) Preparation of Stock Solution
Stock cultures of each organism were established by aseptically transferring each confirmed test organism onto two nutrient agar slants. One set of slants was preserved as stock culture, while the other set served as the working culture. The bacterial cultures on their respective agar slants were stored at 4°C and designated as stock cultures. Additionally, a backup glycerol stock was maintained at a temperature of 20°C.

(D) Inoculum Preparation
The chosen bacterial pathogens were introduced into a nutrient-rich broth, followed by incubation at 37°C for 24 hours. Subsequently, the suspensions were examined, revealing an approximate concentration of 10-5 CFU/ml.

Antibacterial Activity
The antibacterial properties of the compounds were assessed using the agar well-diffusion method at four different concentrations (25, 50, 75, and 100 µl). These compounds were tested against bacterial pathogens such as Staphylococcus aureus and E. coli. Following incubation at 37°C for 18-24 hours, the diameter of the inhibition zone (in millimeters) was measured, and the activity index was computed (Tables-2 to 6).

Table-2: Anti-Bacterial Activity of Standard Ampicillin. Zone of Inhibition Represented in mm.

		Concentration (µg) / Zone of Inhibition (mm)			
S. No.	Strain	25	50	75	100
1	*Staphylococcus aureus*	2	3	3.5	4
2	*E coli*	2	2.5	3	4

Table-3: Anti-Bacterial Activity of Pure SnO_2 and Zone of Inhibition Represented in mm

S. No.	Concentration(µg)/ Zone of Inhibition(mm)				
	Starin	25	50	75	100
1	*Staphylococcus aureus*	0	0.5	1	1.5
2	*E. coli*	0.5	0	0.5	1.5

Table-4: Anti-Bacterial Activity of Z-Sn

		Concentration (µg) / Zone of Inhibition (mm)			
S. No.	Strain	25	50	75	100
1	*Staphylococcus aureus*	0	0	0	0.5
2	*E coli*	0	0	0	0.5

Table-5: Anti-Bacterial Activity of Sn-Zn-A

		Concentration (µg) / Zone of Inhibition (mm)			
S. No.	Strain	25	50	75	100
1	*Staphylococcus aureus*	0	0	1	2
2	*E coli*	0	0	0.5	1

Table-6: Anti-Bacterial Activity of Sn-Zn-N

		Concentration (µg) / Zone of Inhibition (mm)			
S. No.	Strain	25	50	75	100
1	*Staphylococcus aureus*	0	0	0.5	1
2	*E coli*	0	0	0	0.5

The readings were collected in three distinct fixed orientations, and the average values were documented in Fig.-7 to 11.
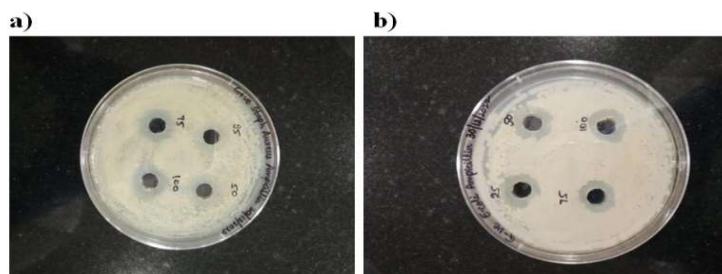

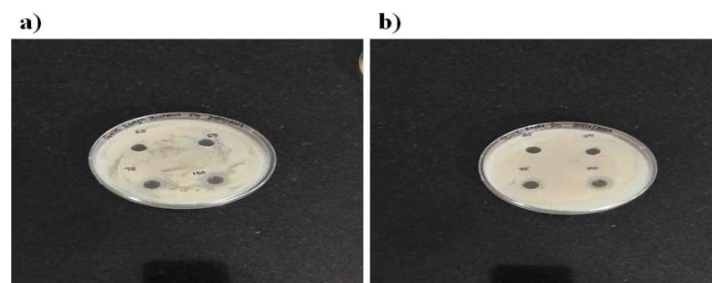Fig.-7: Anti-Bacterial Activity of Standard Ampicillin (a) *Staphylococcus aureus*(b) *E. coli*

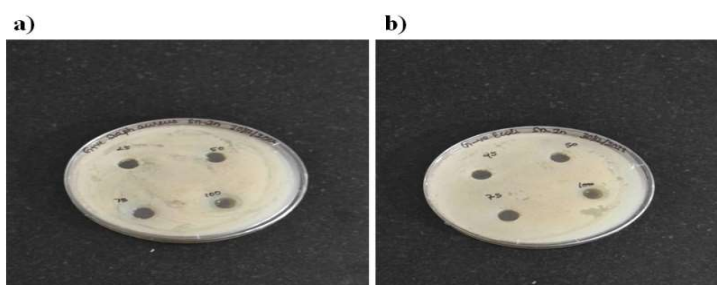Fig.-8: Anti-Bacterial Activity of Sn (a) *Staphylococcus aureus* (b) *E. coli*

Fig.-9: Anti-Bacterial Activity of Z-Sn (a) *Staphylococcus aureus* (b) *E. coli*
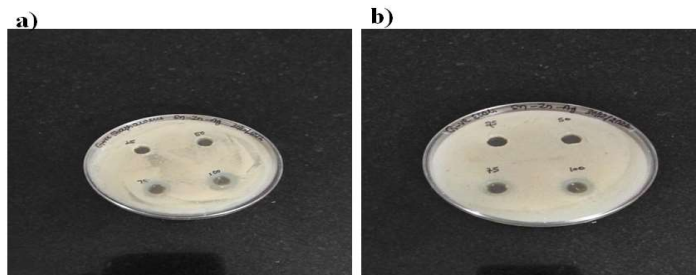
Fig.-10: Anti-Bacterial Activity of Sn-Zn-Ag (a) *Staphylococcus aureus* (b) *E. coli*
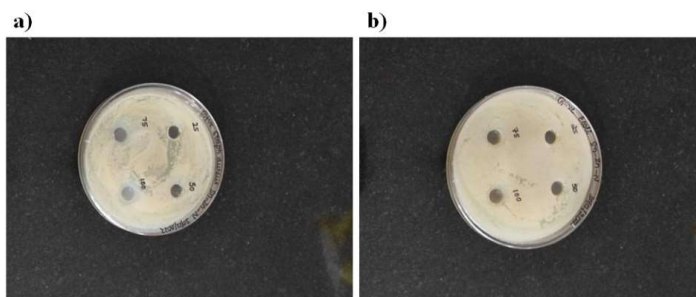
Fig.-11: Anti-Bacterial Activity of Sn-Zn-N (a) *Staphylococcus aureus* (b) *E. coli*

CONCLUSION

Nanomaterials were developed and established using a variety of spectroscopic techniques. Sn^{4+}, Zn^{2+}, Ag^+, N, and other elements are present, according to XPS results. When Zn, N was added to SnO_2, it was discovered that the bandgap energy reduced, the monoclinic phase shifted to the tetragonal phase, the particle size fell, and the surface area increased. SnO_2 doped with Zn and nitrogen exhibits the highest photocatalytic activity. Antibacterial activity of SnO_2 doped with Zn, Ag against strains of Staphylococcus aureus.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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Electromicrofluidic Device for Interference-Free Rapid Antibiotic Susceptibility Testing of *Escherichia coli* from Real Samples

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Abstract: Antimicrobial resistance (AMR) is a global health threat, progressively emerging as a significant public health issue. Therefore, an antibiotic susceptibility study is a powerful method for combating antimicrobial resistance. Antibiotic susceptibility study collectively helps in evaluating both genotypic and phenotypic resistance. However, current traditional antibiotic susceptibility study methods are time-consuming, laborious, and expensive. Hence, there is a pressing need to develop simple, rapid, miniature, and affordable devices to prevent antimicrobial resistance. Herein, a miniaturized, user-friendly device for the electrochemical antibiotic susceptibility study of *Escherichia coli* (*E. coli*) has been developed. In contrast to the traditional methods, the designed device has the rapid sensing ability to screen different antibiotics simultaneously, reducing the overall time of diagnosis. Screen-printed electrodes with integrated miniaturized reservoirs with a thermostat were developed. The designed device proffers simultaneous incubator-free culturing and detects antibiotic susceptibility within 6 h, seven times faster than the conventional method. Four antibiotics, namely amoxicillin–clavulanic acid, ciprofloxacin, ofloxacin, and cefpodoxime, were tested against *E. coli*. Tap water and synthetic urine samples were also tested for antibiotic susceptibility. The results show that the device could be used for antibiotic resistance susceptibility testing against *E. coli* with four antibiotics within six hours. The developed rapid, low-cost, user-friendly device will aid in antibiotic screening applications, enable the patient to receive the appropriate treatment, and help to lower the risk of anti-microbial resistance.

Keywords: antibiotic susceptibility testing; microfluidic; antimicrobial resistance; *E. coli*; multidrug resistance; minimum inhibitory concentration

1. Introduction

The accurate and early detection of microbial infection, followed by appropriate treatment via antibiotic administration, is pivotal in reducing the fatality and severity of the disease in a patient [1,2]. Antibiotics are effective against bacterial infection, by killing the bacteria or inhibiting its growth [3]. Alexander Fleming, a physics scientist, accidentally discovered the first antibiotic, penicillin, to treat bacterial infection. That simple discovery saved millions of lives over decades [4]. Since then, several antibiotics have been prepared and discovered over the years. However, with time, these microorganisms become resistant to drugs. Antimicrobial resistance arises when microbes do not have a more extended response to the medicine, making the infection harder to treat [5]. Therefore, with minimalistic symptoms and disease onset, it is crucial to identify the microorganism and

the antibiotic effective against it. An antimicrobial resistance (AMR) test is often conducted; AMR shows the type and quantity of antibiotic working against the microorganism [6].

Various pathogens, like bacteria, fungi, viruses, and parasites, cause infection and form resistance [7]. Among these, bacterial and viral infections are more prevalent [8]. Pneumonia, diarrhea, and urinary tract infections are the most pervasive bacterial illnesses caused by *Escherichia coli* [9]. *E. coli* is the most known bacterium that causes multidrug resistance [10]. Improper use of antibiotics, multiple illnesses, and prolonged stays in the hospital are critical risk factors for *E. coli* multidrug resistance [11]. Therefore, knowing the antibiotic effect, dosage, and duration before use is essential. Antibiotic susceptibility testing (AST) helps identify the pathogen and the most effective antibiotic against it [12,13]. AST provides information on selecting antibiotics and evaluates the minimum inhibitory concentration. It detects both phenotype and genotype resistance. Genotype is classified based on the presence or absence of a resistant gene, and phenotype is found without the gene mutation. Different techniques are available; among them, disk diffusion is the gold standard for AST, as is quick to execute, can identify many antibiotics in a single test, and allows for a wide range of antibiotic choices. Still, it takes time and cannot provide minimum inhibitory concentration values. Another method is broth dilution [14], which is straightforward, legitimate, and easily accessible but demands more supplies of reagents and introduces more room for error. Moreover, these traditional AST approaches are time-consuming and labor-intensive, requiring skilled laboratory set-up and bulky instrumentation [15]. Often, a time frame of 4–5 days is reportedly needed to study the resistance clinically. Owing to this, the infection increases, and sometimes delays can even be fatal [16]. Hence, developing rapid techniques for measuring antibiotic effectiveness will improve global health and decrease mortality [17]. In this context, miniaturized and microfluidics-based devices provide possible solutions [18,19]. Microfluidic-based devices offer multiple advantages of reduced assay time, low cost, simple operation, and increased testing efficacy [20,21]. However, some microfluidic devices need high resolution. A microfluidic device has recently been designed to separate microbial cells using a ferrohydrodynamic approach. However, the developed device is complex and requires more attention to the environmental effect on fluid flow inside the channel [22]. Hence, microfluidic integrated with electrochemical sensing further improves the detection efficacy and increases the simplicity and sensitivity of detection [23,24].

The present study is an extension of our previous work [25]. Herein, we developed a rapid, sensitive, miniaturized electrochemical device for simultaneous culturing, detection, and antibiotic susceptibility study [26,27]. Here, *E. coli* was used as a model microbe for testing the device. A screen-printed electrode system modified with graphitized meso-porous carbon (GMC) was used for testing [28]. GMC is a high surface area carbon material that helps sensitively detect *E. coli* [29,30]. The microfluidic channel was designed and integrated with screen-printed electrodes. The in-house laser-induced graphene (LIG) heater was fabricated to incubate bacterial culture. Various antibiotics were screened by checking the minimum inhibitory zone, and the one with a more significant inhibition zone was selected for susceptibility testing. Different antibiotic concentrations were prepared, and efficacy was checked using the electrochemical cyclic voltammetry (CV) method. The specificity of antibiotics towards *E. coli* was validated using *Streptococcus pneumoniae*, *Pseudomonas aeruginosa*, and *Shewanella putrefaciens* bacteria. The real sample analysis was done using artificial urine and water samples. The obtained results were further validated with the conventional broth dilution method. To the extent feasible, this is a benchmarking prototype study that has yet to be explored further. The strategy with further optimizations can also be used for other microorganisms in real-time. Figure 1 shows the mechanism of action of different antibiotics to prevent bacterial growth.

Figure 1. Schematic representation of the mechanism of action of antibacterial drugs.

2. Experimental Method

2.1. Materials

Luria broth and Luria agar were procured from Thermo Fisher Scientific, Delphi, India. Potassium chloride, carbon ink, glass slides (75 × 50 mm), ammonium phosphate, sodium sulfate, ammonium diphosphate, magnesium chloride, calcium chloride, creatinine, and urea were purchased from Sigma Aldrich, Ltd. (Burlington, MA, USA). *E. coli* culture was acquired from the Biological Science Department, BITS Pilani Hyderabad campus. Clavam 625 (amoxicillin and clavulanic acid), Zenflox 200 (ofloxacin), Monocef-O 200 (cefpodoxime), Cifran 500 (ciprofloxacin), and Azee-500 (azithromycin) were purchased from a local medical store. Polydimethylsiloxane (PDMS) was purchased from Delta Silicon, Mumbai, India. A CO_2 laser (VLS 3.20) was procured from Universal Laser Systems, Scottsdale, AZ, USA.

2.2. Development of Three-Electrode System and Microfluidic Device

A three-electrode system was fabricated using the screen-printing technique. The design of the requisite dimension was first drawn on SolidWorks software. A polyvinyl chloride (PVC) sheet was attached to a glass side (75 × 50 mm), and the laser was scribed over the PVC sheet to prepare the mask. Carbon ink was laid down over the obtained mask with the help of a squeeze and kept in the oven for 30 min at 60 °C. The PVC sheet was removed after drying, and the screen-printed electrodes were obtained [31]. Figure 2 depicts a detailed schematic of the fabrication process.

Figure 2. Schematic for the development of a three-electrode system using the screen-printing technique.

A mold (2 × 1.4 × 17 mm^3) was prepared on an acrylic sheet to develop the microfluidic device. To create a PDMS mixture, epoxy and curing agent were mixed in a 10:1 ratio and degassed for 30 min to remove oxygen bubbles. Following this, PDMS was run over the mold and baked for an hour at 60 °C. Post-curing, the reservoir was cut from the mold and bonded over the three-electrode system using the plasma bonding method. The developed

microfluidic device integrated with the laser-induced graphene (LIG) heater is shown in Figure 3. The details of the fabrication scheme for screen-printed electrodes, microfluidic device fabrication, and its integration, as well as how to prepare bacteria samples, were covered in greater depth in our previous research [25].

Figure 3. (**A**) A miniaturized device integrated with (**B**) a laser-induced graphene (LIG) heater provides temperature, and copper tape provides electrical contacts connected to the voltage regulator. (**C**) The LIG heater captured by a thermal camera after heating while providing a voltage of 2.5 V.

2.3. Fabrication of LIG Heater

For the fabrication of the LIG heater, a polyamide sheet of the required dimension of 25×25 mm was initially pasted onto a glass slide surface using double-sided tape. The CO_2 laser (VLS 3.60) was exposed on the polyimide sheet with power and speed of 6.5% and 4.5% to obtain laser-induced graphene [32]. After engraving, the obtained thickness was 50 µm. Electrical contacts were provided on the fabricated LIG film using copper tape and silver ink. The thermal factor was calibrated earlier by varying the potential and noting the temperature. A temperature of 37 °C was maintained by applying a potential of 2.5 V. A thermal camera was used to keep track of the achieved temperature. Figure 3C shows the temperature of the LIG heater, which was maintained at 37 ± 10 °C.

2.4. Effect of Antibiotic on E. coli

Electrochemical analysis was used to determine the effect of antibiotics on bacterial growth. A Potentiostat (CHI 1030E) was utilized to record the electrochemical response. A three-electrode setup was employed, with a reference electrode of Ag/AgCl, a working electrode of GMC, and a counter electrode of plan carbon ink.

2.5. Evaluation of Real Samples

The real samples used for analysis were synthetic urine and tap water [14]. The synthetic urine was prepared by adding all dried components to sterile water. Normal urine is a mixture of organic compounds such as urea, creatinine, and uric acid and inorganic substances like ammonia, sulfates, chloride, and phosphates. The composition of prepared synthetic urine is provided in Table 1.

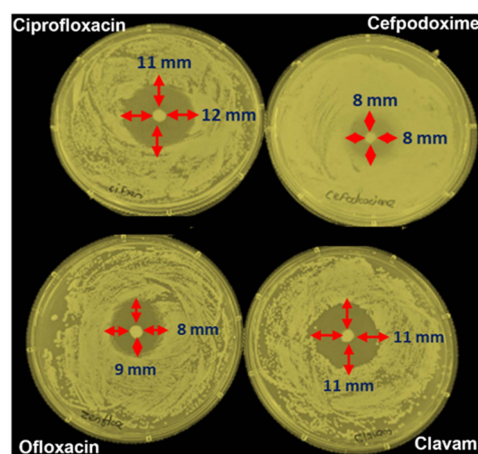**Table 1.** Composition of synthetic urine.

Components	Quantity (mg/L)
Potassium Chloride (KCl)	2000
Sodium Sulfate (Na_2SO_4)	2000
Ammonium Phosphate (($NH_4)_3PO_4$)	850
Ammonium Diphosphate (($NH_4)_3PO_4$)	850
Calcium Chloride ($CaCl_2$)	250
Magnesium Chloride ($MgCl_2$)	500
Urea (CH_4N_2O)	600
Creatinine ($C_4H_7N_3O$)	50

3. Results and Discussion

3.1. Off-Chip Minimum Inhibitory Concentration (MIC) Measurement

The MIC describes the resistance or susceptibility of the particular bacteria toward valuable antibiotics. The model microorganism used was *E. coli* (DH5α strain) for MIC calculation. An agar plate containing Luria–Bertani (LB) broth was used to sustain *E. coli* cells. A colony of *E. coli* cells was removed from the agar plate and suspended in 5 mL of LB liquid media. Overnight at 37 °C, the cells were cultured in the medium on a shaker at 200 rpm. After that, fresh LB medium was used to dilute the cell suspension until it reached an optical density of 0.01 at 600 nm.

The antibiotic stock solution (1 mg/mL) of cefpodoxime, ofloxacin, amoxicillin, clavulanic acid, and ciprofloxacin was prepared in sterile water. Several concentrations, ranging from 100 to 500 g/mL, were prepared from the stock solution, and the MIC was measured using a disk diffusion approach. The LB agar media was prepared and poured into a Petri plate. After solidifying the agar gel, the bacterial culture was spread over the plate. Using sterile forceps, an antibiotic disk of cefpodoxime, ofloxacin, amoxicillin, clavulanic acid, and ciprofloxacin was applied to the plate and incubated for 12 to 24 h at 37 °C. The minimum inhibition zone formed at the edge of the antibiotic disk was calculated. Figure 4 shows the disk diffusion method for MIC calculation. The distance from the antibiotic disk to the inhibition area for every antibiotic was calculated. The one that covered more inhibition zones, i.e., ciprofloxacin, was selected for a real sample and interference study.

Figure 4. Disk diffusion method for calculation of minimum inhibitory concentration.

3.2. Electrochemical Detection of Antibiotic Effect over the Bacterial Growth

To carry out the electrochemical investigation of bacterial growth inhibition, 100 µg/mL antibiotic concentration of cefpodoxime, amoxicillin and clavulanic acid, ciprofloxacin, and ofloxacin with bacterial culture media was injected into four miniaturized reservoirs through the inlet. Before the analysis, the reservoir was washed with 0.1 M PBS to prevent cross-contamination. The LIG heater was used to incubate the bacterial culture throughout the experiment, which is necessary for bacterial growth. The electrochemical detection was carried out using CV for 6 h, and after every hour, the response was recorded. Figures 5 and 6 show the electrochemical reactions of the control sample (without antibiotic) and four antibiotics, and their respective calibration plots are given in Figure 7. According to the minimum inhibition zone study, out of four antibiotics, ciprofloxacin was more effective toward *E. coli* bacterial inhibition. The bacterial concentration would decline in the device with increased time and a constant temperature. In Figure 6, the current value increases with incubation time because of antibiotics on bacterial growth. Usually, when the bacteria grow, they accumulate over the electrode surface and block ion flow, decreasing the peak current value, which we can see in Figure 5 without antibiotic response. The antibiotic helps to increase the transfer of ions in the media, which was blocked by the growth of bacteria, as shown in Figure 6 [32].

(**a**)　　　　　　　　　　　　　　(**b**)

Figure 5. A cyclic voltammetric graph of bacterial culture without antibiotics (**a**) and its respective calibration plot (**b**).

Figure 6. Cyclic voltammetric graphs of four antibiotics at concentrations of 100 μg/mL. The experiment was performed in the microfluidic device for 6 h, and the response was recorded at intervals every 1 h. (**A**) Ofloxacin, (**B**) cefpodoxime, (**C**) ciprofloxacin, (**D**) amoxicillin and clavulanic acid.

Figure 7. Calibration plot of four antibiotics was performed in the microfluidic device for 6 h. (**A**) Ofloxacin, (**B**) cefpodoxime, (**C**) ciprofloxacin, (**D**) amoxicillin and clavulanic acid.

3.3. Interference Study

The specificity of the Clavam antibiotic toward *E. coli* was checked in the developed microfluidic device. Four variants, namely *Streptococcus*, *Shewanella*, *Pseudomonas*, and *E. coli*, were tested with Clavam antibiotic. The first *E. coli* with Clavam antibiotic was injected into the device, and CV response was recorded, Figure 8a. *Pseudomonas*, *Streptococcus*, and *Shewanella* were then added into the same device, and the CV response was measured. A similar current histogram for *E. coli* and an additional variant mixed with *E. coli* is shown in Figure 8b. The apparent difference in the inhibition values for *E. coli* and other bacterial species confirms that ciprofloxacin did not affect *Shewanella putrefaciens*, *Pseudomonas aeruginosa*, and *Streptococcus pneumoniae* [25]. The efficiency of ciprofloxacin against different pathogens was negligible or less than 10%, indicating that it is solely effective against *E. coli* species or that the developed sensor is specific toward *E. coli* species.

Figure 8. CV graph for specificity study of antibiotics (Ant) toward *E. coli*, *Pseudomonas aeruginosa* (PA), *Streptococcus pneumoniae* (Stp), and *Shewanella putrefaciens* (Sch). CV graph responses (**a**) and respective total current plot variation (**b**).

3.4. Antibiotic Susceptibility Testing Using Synthetic Urine

A urine sample is mainly used for examining a medical condition. However, obtaining the same quality urine for many illness detections takes time and effort. Hence, synthetic urine is used for experimentation purposes [33]. Along with this, water pollution due to microorganisms is also a significant issue that causes waterborne diseases. Therefore, there is a critical need to detect the microbial pollution of water [34]. Consequently, urine and water samples were selected for real sample analysis. Before testing, synthetic urine and tap water were autoclaved to avoid any microbial contamination.

E. coli culture was inoculated into the synthetic urine and tap water before being injected into the device. The electrochemical response was checked for 7 h at hourly intervals. The CV response of a water sample and synthetic urine is shown in Figure 9. The rise in current under the influence of antibiotics was observed [35]. As time increases, the current values also increase because the antibiotic decreases the growth of bacteria. The volume of ions in the urine increases the flow of ions, increasing the current value. This signifies the effect of antibiotics on the growth of bacteria.

Figure 9. CV graph for real sample analysis performed in the microfluidic device for 7 h in (**A**) tap water and (**B**) synthetic urine.

4. Conclusions

This study developed a label-free, simple, cost-effective, miniaturized electrochemical microfluidic device to diagnose microbial resistance and bacterial infection rapidly. The designed device demonstrated remarkable sensitivity toward *E. coli* and detected the antibiotic susceptibility within a concise 6-h timeframe. As part of our methodology, a three-electrode system was added to our miniaturized platform, with the working electrode modified with GMC, the reference electrode using Ag/AgCl, and the counter electrode composed of bare carbon ink. Electrochemical detection was performed using cyclic voltammetry, which enabled accurate measurements. The working electrode was modified with GMC to improve sensor performance and increase precision. Four antibiotics of the same concentration were tested in the susceptibility study, and the interference of the antibiotic toward *E. coli* was detected. Further antibiotic susceptibility study was performed in both artificial urine and water samples, ensuring the versatility and robustness of our device's performance. The obtained outcomes were validated with the conventional approach, confirming the reliability of our findings. To address the pressing demand for rapid and accurate antibiotic susceptibility testing, integration with Cyber-Physical System (CPS) augmented techniques, like data mining and machine learning, with essential automation will aid in diagnosing antibiotic susceptibility rapidly. These technologies will advance the diagnostic process and enhance its accuracy. Moreover, as bacterial resistance to conventional treatments continues to rise, there is a critical need for technologies that accurately distinguish between resistant, susceptible, and persistent bacterial strains. These advancements pave the way for precision medicine, yielding optimal diagnostic results in the ever-evolving landscape of bacterial infections.

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ORIGINAL ARTICLE

Anti-pathogenicity of *Acanthus ilicifolius* leaf extracts against *A. hydrophila* infection in *Labeo rohita* fingerlings

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Abstract

Antibiotic resistance has become one of the inevitable barrier in aquaculture disease management. Herbal drugs has evolved to be the novel ways of combating drug resistant pathogens. In the current investigation, leaf extracts of mangrove plant, *Acanthus ilicifolius* were assessed for in vitro studies, among the selected four extracts, methanol extract has expressed highest antibacterial activity against *P .aeruginosa* (4 ± 0.3 mm), *A. hydrophila* (5.9 ± 0.5 mm), *S. aureus* (3.5 ± 0.7 mm) and *B. subtilis* (2.9 ± 0.5 mm) and antioxidant activity, DPPH (81.3 ± 1.0 AAEμg/ml) and FRAP (139.1 ± 1.5 AAEμg/ml).TPC and TFC were higher in the methanolic extract and has exhibited positive correlation with both DPPH and FRAP assays. Considering the in vitro efficiency, methanol extract was purified successively by column and thin layer chromatography and characterisation by GC–MS unveiled the presence of 2-Propanethiol, Trimethylphosphine, Pentanoyl chloride, Dimethylhydroxymethylphosphine and Propanedinitrile, ethylidene. *A. hydrophila* infected *L. rohita* fingerlings has survival percentage 81% and 94% in extract treated groups over 0% in negative control and 71% in positive control.

Keywords *Acanthus ilicifolius*, Antibacterial activity, Antioxidant activity, GC–MS, *L. rohita*

Introduction

Over the past two decades aquaculture has received huge attention as one of the rapidly developing food producing industries (Edwards et al. 2019). Economically it has been supporting 10–12% of global population (FAO 2014). Freshwater aquaculture accounts 95% of the total aquaculture production in India (DADF 2017), of which the carp culture is most preferred due to its fast growth and consumptive value (Ngasotter et al. 2020). Fin fish and shell fish has become invaluable sources of protein and essential nutrients in the human diet of day to day life (Garlock et al. 2020). In the recent past, the demand for the fish protein was increased massively. In order to meet the demand, the culture practices were progressed towards semi intensive and intensive methods. Aquaculturists are ensuing vertical expansion of the culture with high stocking densities which leads to water quality deterioration, stress, immune suppression in the host and spread of infectious diseases (Mishra et al. 2017; Dawood 2021). Antibiotics of class beta lactams, tetracyclines, quinolones, sulphonamides, aminoglycosides, lincosamides, nitrofurans, chloramphenicols and macrolides (Sun et al. 2020) are mainly destined to treat the bacterial infections (Miranda 2012). Frequent use of these antibiotics as therapy, metaphylaxis and prophylaxis will eventually results in the development and propagation of multidrug resistant genes in the bacteria, effects nontarget organisms, accumulation of residues in the fish tissues and surrounding environment (Okoye et al. 2022). The drug resistant genes and antibiotic residues get

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disseminated to the consumer (Heuer et al. 2009; Done et al. 2015) and impose perturbation of intestinal microbiota, mutagenicity, hypersensitivity, aplastic anaemia and carcinogenicity (Liu et al. 2017).

Phytocompounds has become a promising therapeutic alternative in the place of antibiotics (Zhang et al. 2022), they are biodegradable, eco-friendly, treats the disease without instigating anti-drug resistance (Direkbusarakom 2004). The phytocompounds enhances digestion, feed conversion ratio, enzyme activity, protein synthesis, phagocytic activity, healing power, immunity (specific and non-specific) in the fish. Mangroves are obligate halophytic, stress tolerant plants (Wang et al. 2011) with structurally diverse and unique bioactive compounds, act as prospective source for the development of novel therapeutic products (Alvin et al. 2014).

Phytocompounds of *Acanthus* species possess remarkable pharmacological properties viz., anti-microbial, anti-inflammatory, antioxidant, antinociceptive, antiparasitic. *Acanthus ilicifolius* L. vernacularly known as Alasyakampa, Alchi of order Magnoliopsida and family Acanthaceae with spiny lanceolate leaves and can grow up to a height of 3 m. Traditionally, the plant has been used for dyspepsia, paralysis, asthma, headache, rheumatism, and skin diseases (Patel et al. 2020; Matos et al. 2022). The current work focused on in vitro and in vivo application of bioactive compounds of *A. ilicifolius* against *Aeromonas hydrophila* and also studied free radical scavenging efficiency.

Material and Methods
Plant collection and extraction
The present study was aimed to assess the efficacy of phytocompounds in *A.ilicifolius* leaves as a therapy for bacterial diseases in fish culture. Fresh leaves were collected on 12.04.2021 from Gilakaladindi mangrove forest (16.14° N, 81.16° E), 6 km East to Machilipatnam, Andhra Pradesh, India. *A.ilicifolius* confirmation was done by taxonomist from the Dept. of Botany and documented (AI-142021) in the museum, Acharya Nagarjuna University, Andhra Pradesh, India. The remnants of dust particles were removed by washing and leaves were shade dried. The desiccated leaves were ground to fine powder, mixed with petroleum ether, ethyl acetate, methanol and double distilled water in a ratio of 1:10 (w/v), extracts were prepared by soxhlet technique maintained at suitable temperature for 7 h. Filtered extracts (Whatman No.1) were concentrated by using rotary evaporator.

Qualitative analysis of phytochemicals
Standard protocols of (Harborne 1998) were followed to detect the presence of phytochemicals (saponins, tannins, flavonoids, steroids, terpenoids, glycosides, carbohydrates, proteins, phytosterols, cardiac glycosides, alkaloids, phenols, reducing sugars, anthraquinones) in leaf extracts.

Agar well diffusion assay and minimum inhibitory concentration
The method of (Rios et al.1988) was adopted for determining the antibacterial activity of the leaf extracts. 100 µl each of *Pseudomonas aeruginosa* (MTCC1934), *Aeromonas hydrophila* (MTCC1739), *Staphylococcus aureus* (MTCC1430) and *Bacillus subtilis* (MTCC121) were inoculated individually on solidified Mueller Hinton Agar (MHA) petri plates. The wells (6 mm diameter) were bored by sterile cork- borer and filled with 40 µl of leaf extracts and oxytetracycline of 20 µg/ml concentration which was used as positive control. The inhibitory zones (mm) were measured after 24 h incubation at 37 °C.

(Benger et al. 2004) protocol of broth dilution was adopted for the minimum inhibitory concentration (MIC). To the sterile tubes with 10 ml of MHA broth, the methanol leaf extract of *A.ilicifolius* leaf was added in a serial concentration of 10 to 100 µg/ml except for the control. 0.5 ml (1×10^6 CFU) *A.hydrophila* was added to each tube. After 24 h of incubation at 37 °C, the concentration of the extract that inhibited visible bacterial growth was noted as the MIC.

Antioxidant activity
Total phenol content (TPC) and total flavonoid content (TFC)
For TPC, Folin-Ciocalteu protocol (Ali et al. 2014) was followed. 1 ml of 0.5N folin-ciocalteu reagent was added to 250 µl of the sample and left undisturbed for 5 min. To this 1.5 ml of 20% (w/v) sodium carbonate solution was added, vortexed and incubated for 90 min at 37 °C. The absorbance was noted at 760 nm. TPC of the leaf extract was presented as mg GAE/g DW (mg gallic acid equivalent per gram dry weight).

TFC was determined by aluminum chloride colorimetric method (Koolen et al. 2013). 250 µl of the extract was mixed with 2% methonolic aluminum chloride (250 µl), incubated for 45 min at room temperature and the absorbance was measured at 430 nm in UV–vis spectrophotometer. TFC was expressed as mg rutin equivalent per gm of body weight (mg RE/g DW).

DPPH radical scavenging assay
(Blios 1958) method of DPPH assay was followed for the determination of antioxidant activity. Known quantity of DPPH solution was mixed with 31.25, 62.5, 125, 250, 500 µg/ml of leaf extracts, incubated in dark for 30 min. At 517 nm, absorbance of the coloured solution was

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measured. Methanol and ascorbic acid were used as the blank and standard respectively. The percent DPPH radical scavenging activity of the leaf extracts was calculated using (A0-A1)/A0×100, A0 and A1 are the absorbance of the control and sample respectively.

IC_{50} of leaf extracts against DPPH free radical was obtained by plotting a graph between concentration and % free radical scavenging activity of the extract, the value was calculated by interpolation of linear regression analysis.

FRAP assay

(Benzie and Strain 1996) protocol was followed for the FRAP assay. The FRAP reagent, 1 volume of 20 mM $FeCl_3$ and 1 volume of 40 mM HCl containing 10 mM 2,4,6-tri (2-pyridyl-s-triazine) (TPTZ) were added to 10 volume of 300 mM of acetate buffer (1:1:10 v/v). To this reagent 15.62, 31.25, 62.5, 125, 250, 500 μg/ml of leaf extracts were added, incubated for 15 min at 37 °C. At 593 nm the optical densities were measured. Ascorbic acid was standard and the results for both DPPH and FRAP were noted as μg of AAE per ml.

Separation and purification of the extracts
Column chromatography

Methanol leaf extract (20 g) of *A.ilicifolius* were passed through the column packed with 100 to 200 mesh sized silica gel. The mobile phase acetone:methanol (9:1 to 1:9) were used for the elution of the sample. Fractionation of the samples was carried by gradient separation of the mobile phase. The similar coloured elutes were pooled, labelled and evaluated for the antibacterial and antioxidant activity.

Preparative TLC

The active fractions that yielded high antibacterial and antioxidant activity were further separated and purified by preparative TLC. The glass plates (250μ thickness, 20×20 cm) were coated with slurry; 30 g of silica gel and small quantity of $CaSO_4$ in 60 ml triple distilled water. The plates were dried at room temperature for 10 min, at 105 °C in hot air oven for 1 h and for 2 h in a desiccator.

The known amount of active fraction was placed on TLC plate and was kept in solvent system, 12:6:3 of butanol: acetone: water. The bands formed by the capillary movement of the solvent were observed under UV light illumination. The procedure was repeated to get the bands with good resolution and in multiple number. The multiple scrapings of similar Rf value bands were pooled and tested for both antibacterial and antioxidant activity.

GC–MS

GC–MS analysis was carried out using an Agilent (5977B) single quadrupole GC/MS followed towards mass detector. Absorbed silica capillary column made of 95% dimethylpolysiloxane and 5% phenyl (HP-5MSI; length: 90 m, diameter: 0.250 mm and foil: 0.25 m). Maintained injector temperature of 25 °C, a fontal oven temperature of 90 °C, a gradual increase to 200 °C at a rate of 3 °C/min for 2 min, and a final increase to 280 °C at a rate of 15 °C/min for 2 min. Helium 99.999% was the carrier gas with a column flow rate of 1 μm / min. The fixed interface temperature between GC and MS was set to 280 °C, and the electron ionisation system on the MS was in scan mode. The examined mass range was between 50 and 550 m/z, and the MS quad and source temperatures were computed at 250 °C and 280 °C, respectively. NIST spectral library was utilized to look for and identify each component.

In vivo studies
Experimental design

Pathogen free healthy *Labeo rohita* fingerlings, 9.5 ± 0.5 cm and 11 ± 0.9 g were separated from the random sample, acclimatised in 40L capacity tubs with 24 h aeration for 10 days prior to the experimentation. Fishes were fed twice daily with commercial feed of 5% bodyweight. From the bottom of tubs, leftover feed was siphoned out and 1/3rd of the water was replaced at late afternoon to reduce water toxicity caused by excreta (ammonia).

On the 11th day, acclimatised healthy fingerlings were segregated into five groups with nine in each (n = 3). Except control all the experimental groups were starved for 24 h.

Group I: Control (Neither infected nor treated)

Group II: Negative control (Infected but not treated).

Group III: Positive control (Infected and treated with Oxytetracycline).

Group IV: Infected and treated with crude leaf extracts.

Group V: Infected and treated with purified leaf extracts.

12th day of the experiment, group II to V infected with 0.5 ml of *A. hydrophila* (10^3 CFU). Subsequently, from 13th day Group III, IV and V were treated with oxytetracycline 2.5 mg/ kg body weight, crude extract 4 mg/kg body weight and purified extract 2.5 mg/ kg body weight of *A.ilicifolius* respectively for 6 days. Pathogen and treatment for the fingerlings was administered through feed and dosages were determined by pilot studies.

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Confirmatory tests of *A. hydrophila*

Followed Koch's postulates criteria; bacteria was isolated from moribund fingerlings, cultured, diseased healthy fingerlings by inoculating the cultured bacteria. Further the bacteria was re-isolated, compared the bacteria used in the present experiment and confirmed *A. hydrophila* as pathogenic. Morphological and biochemical confirmatory tests were conducted for *A. hydrophila* (Gilardi 1967).

Estimation of catalase (CAT) and superoxide dismutase (SOD)

Hepatic tissue of all the experimental groups were homogenised using 15 mM Tis-HCl buffer at pH 7.4, centrifuged for 20 min at 10,000 rpm, 4 °C and supernatant was used for estimation of protein, CAT and SOD by (Bradford 1976; Aebi 1984; Misra and Fridovich 1972) methods respectively.

0.05 ml of sample was mixed with 1.95 ml phosphate buffer and 1 ml hydrogen peroxide and the decreased absorbance was measured at 240 nm against blank. In the presence of CAT, H_2O_2 break down into H_2O and O_2. CAT levels were estimated by measuring the decrease in hydrogen peroxide (H_2O_2) concentration in the mixture. For estimation of SOD, sample (0.01 μl) was mixed with carbonate buffer (2.96 μl), epinephrine (0.01 μl), EDTA (0.02 μl), incubated for 2 min at room temperature and measured the absorbance at 450 nm. CAT and SOD levels were expressed in units of enzyme per mg of protein.

Statistical analysis

The relationship between TPC, TFC and antioxidant activity (FRAP and DPPH) were calculated by Pearson's correlation coefficient. SPSS software was used for the statistical analysis.

Results

Qualitative analysis of Phytochemicals

A.ilicifolius leaf extracts disported positive results for all the tested phytochemicals except for anthraquinones (Table 1). Maximum number of phytochemicals got extracted into the methanol.

The results of the work were presented in mean ± S.D, with n = 6 .

Antibacterial activity and minimum inhibitory concentration

The antibacterial activity of the extracts exhibited varied inhibitory zones against gram positive (*S. aureus* and *B.subtilis*) and gram negative bacteria (*P.aeruginosa* and *A. hydrophila*) (Additional file 1: Table S1). Highest

Table 1 Qualitative analysis of phytochemicals in *A.ilicifolius* leaf extracts in solvents

Phytochemicals	Petroleum ether	Ethyl acetate	Methanol	Aqueous
Saponin	−	+	+	+
Tannin	−	-	+	-
Flavonoid	+	+	+	+
Steroid	+	−	−	−
Terpenoid	+	−	−	−
Glycosides	−	+	−	+
Carbohydrates	−	−	+	−
Proteins	+	−	+	−
Phytosterols	+	−	+	+
Cardiac glycosides	+	+	+	+
Alkaloid	+	-	+	+
Phenols	+	+	+	+
Reducing sugars	−	−	+	+
Anthraquinones	−	−	−	−

+ presence, − absence
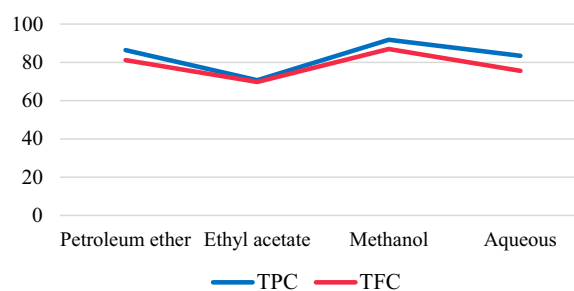
Fig. 1 TPC and TFC of *A.ilicifolius* leaf extracts

zones of range 2.9 ± 0.5 mm to 5.9 ± 0.5 mm was exhibited by methanol extract against all the strains. Close affinity was observed between the inhibitory zones of standard, oxytetracycline (6.4 ± 0.8 mm) and methanol extract (5.9 ± 0.5 mm) against *A.hydrophila.*

MIC determines the concentration of the drug (leaf extract) to which the pathogen is susceptible. The visible growth of *A.hydrophila* was prevented at 49 μg/ml concentration of methanol leaf extract of *A.ilicifolius.*

Antioxidant activity

Total phenol and flavonoid content were higher in methanol extract followed by petroleum ether, aqueous and ethyl acetate extracts (Fig. 1). The DPPH and FRAP antioxidant activity assays of the extracts was measured at different concentrations (Figs. 2 and 3). Among the extracts, methanol extract has resulted highest DPPH; 81.3 ± 1.0 AAE μg/ml and FRAP; 139.1 ± 1.5 AAE μg/ml activity at 500 μg/ml concentration. IC_{50} of the extracts

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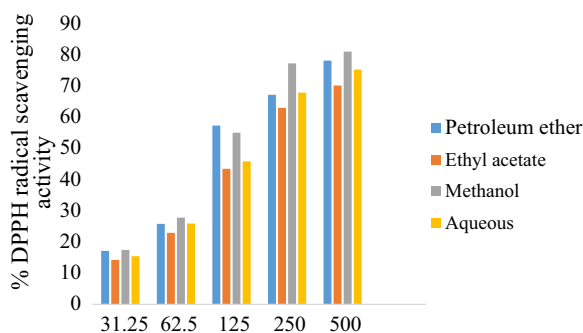
Fig. 2 DPPH assay of *A.ilicifolius* leaf crude extracts, results were expressed in Ascorbic acid equivalents (μg/ml)
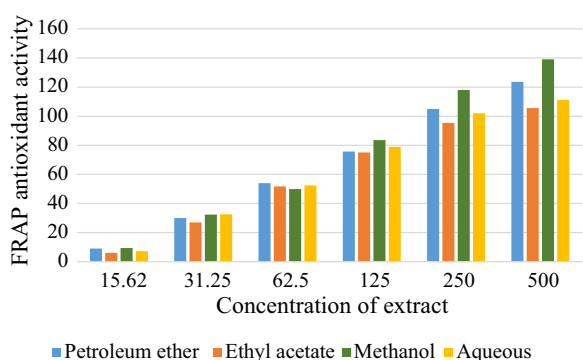
Fig. 3 FRAP assay of *A.ilicifolius* leaf crude extracts, results were expressed in Ascorbic acid equivalents (μg/ml)

ranged from 118.6 μg/ml by methanol to 164.8 μg/ml by aqueous extracts. Lower IC_{50} reflects higher antioxidant ability (Roy and Dutta 2021) inferring to the highest antioxidant activity of methanol. TPC and TFC of the all extracts has showed a linear correlation with the antioxidant activity (FRAP and DPPH) (Fig. 4 represents correlation of methanol extract).

Separation and purification of the extracts
Column chromatography
Phytocompounds in the methanol extract was separated. 14 fractions were obtained, grouped into five and pooled in accordance to their colour (Table 2). No bioactivity was observed in fraction B. Fraction E failed to inhibit the growth of *A.hydrophila* and D has no DPPH radical scavenging activity. Pooled fractions of A and C exhibited both antibacterial and antioxidant activity. Despite of the antibacterial and antioxidant activity shown by A and C, maximum inhibition of *A.hydrophila*, 7.5 ± 0.8 mm and %DPPH free radical scavenging activity, 83.2 ± 0.8% was reported in fraction A.

Preparative TLC
Highest bioactivity of Fraction A might be due to the presence of potential antibacterial and antioxidant phytocompounds. For further separation of compounds pertained to bioactivity, this fraction was eluted in TLC, separated into three bands with different Rf values. Phytocompounds of each band was subjected to antibacterial and DPPH scavenging activity, (Table 3). AM1 and AM3 bands has lesser antibacterial and antioxidant activity. Band AM2 has highest antibacterial, 13.5 ± 1.2 mm and %DPPH radical scavenging, 88.1 ± 0.9% activity.

GC–MS
GC–MS was adopted to characterise the compounds in AM2 responsible for antibacterial and antioxidant activity. Spectral finger print of the phytocompounds detected 5 compounds with corresponding retention time, molecular mass, molecular formula and peak area (Table 4 and Fig. 5A–E).

In vivo studies
The therapeutic efficiency of *A.ilicifolius* crude and purified methanol leaf extract was assessed in in vivo against *A.hydrophila* infection in *L.rohita* fingerlings. Group I fingerlings, being control were healthy and exhibited 100% survival until end of the experiment. Fingerlings of group II to V, which were deliberately exposed to the *A.hydrophila*, showed behavioural and morphological alterations viz., frequent hitting against the walls, change in swimming patterns, gill necrosis, septicaemia, haemorrhages and abrasion of fins, rotting of caudal region, abdominal dropsy, bulged eyes/ popped eye, red skin lesions and stick out of scales. These clinical manifestations were more pronounced in group II as the fingerlings were untreated with antibiotic or plant extracts and 0% survival was recorded. A clear external and internal signs were noticed in the post mortem of diseased fingerlings of all groups; accumulation of bloody fluids in intestine and externally body looks balloon, haemorrhages in hepatic tissue, kidney necrosis, hypertrophy and darkened spleen, disfigured internal organs. Oxytetracycline treated fingerlings showed 71% survival and those treated with crude and purified leaf extracts has showed 81% and 94% survival respectively (Additional file 1: Table S2).

The levels of hepatic enzymes CAT and SOD refers to capacity of free radical suppression. In experimental groups; fingerlings of group V recorded highest levels of CAT, 20.7 ± 1.2 and SOD, 17.6 ± 1.1. The enzyme levels in groups II to IV were lesser than the group V and group I. However, exception was noticed in SOD level of group IV (Fig. 6).
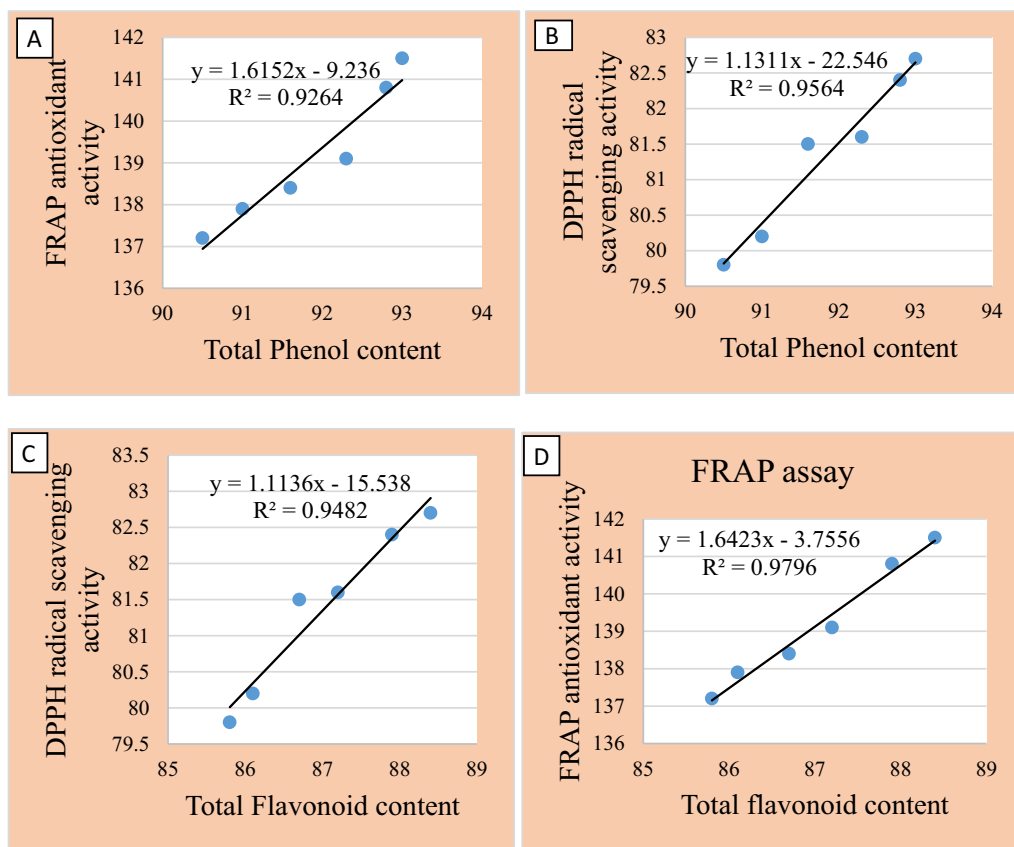
Fig. 4 Correlation between TPC,TFC and antioxidant activity of methanol leaf extract **A** TPC vs FRAP, **B** TPC vs DPPH, **C** TFC vs DPPHand **D** TFC vs FRAP

Table 2 Fractions, their antibacterial and antioxidant activity of *A.ilicifolius* Methanol leaf extract

Solvent system	Fractions	Code	Colour/ Characteristic	Zone of inhibition (mm) against *A. hydrophila*	% DPPH radical scavenging activity
100:0	1–3	A	White	7.5 ± 0.8	83.2 ± 0.8
90:10	–	–	–	-	–
80:20	4–6	B	Pale yellow	-	–
70:30	–	–	–	-	–
60:40	7–8	C	Yellow	2.1 ± 0.4	43.4 ± 1.1
50:50	–	–	–	–	–
40:60	–	–	–	–	–
30:70	–	–	–	–	–
20:80	9–11	D	Orange	1.2 ± 0.6	–
10:90	12–14	E	Yellow	–	38.7 ± 0.9
0:100	–	–	–	–	–

Confirmation of *A. hydrophila*

A cluster of morphological and biochemical confirmatory tests confirmed the bacteria as *A.hydrophila* (Additional file 1: Table S3).

Discussion

Frequent outburst of infectious diseases is one of the severe threats in aquaculture leading to monetary loss. For the last few decades, the therapeutic knowledge of

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Table 3 TLC bands and their Antibacterial and antioxidant activity of *A. ilicifolius* Methanol leaf extract

Bands	Rf value	Zone of inhibition (mm) against *A. hydrophila*	% DPPH radical scavenging activity
AM1	0.17	1.6 ± 0.5	13.6 ± 1.3
AM2	0.24	13.5 ± 1.2	88.1 ± 0.9
AM3	0.29	2.4 ± 1.1	24.2 ± 1.8

treating these infectious diseases was confined to synthetic antibiotics and chemical drugs. Imprudent use of antibiotics inflict stress, dysbiosis of microbiota, metabolic malfunctioning, immune suppression, accumulation of residues in the tissues of fish (Limbu et al. 2021). On long run these therapeutic practices were increasing the pathogenic resistance, residual accumulation in the water, fish and consumers and there is a need to limit the usage of these drugs (Zhang et al. 2022). Medicinal flora and mangroves in specific are used in traditional practices of disease control and are therapeutic agents for ulcers, diabetes, tumors, skin diseases, inflammation etc. (Mitra et al. 2021), *A.ilicifolius* exhibit anticancer, antiviral, anti-inflammatory (Aisiah et al. 2022), *Excoecaria agallocha*; antioxidant, anti-filarial, antiviral (Abeysinghe 2010), *Bruguiera gymnorrhiza*; anti-analgesic, antioxidant, anti-diarrhoeal (Mahmud et al. 2017).

In the present study, *A.ilicifolius* leaf extracts functioned efficiently against the selected fish bacterial pathogens. Application of phytotherapeutics is bestowing positive results in the fish disease management (Zhu 2020). Leaf extracts of the selected mangrove plant has bioactive secondary metabolites considerably responsible for the anti-pathogenic activity. In similar with the present findings, tannins, saponins, carbohydrates, proteins, phenols, cardiac glycosides, were reported in the methanol (Ganesh and Vennila 2011; Pothiraj et al. 2021) and ethanol extract (Aisiah et al. 2022) of *A.ilicifolius*. Tannins, alkaloids and steroids inhibit the bacterial pathogenicity by inactivating

bacterial adhesion cells, disrupting cell membrane composition and DNA synthesis, flavonoids and phenols scavenge the free radicals released during infection (Dewanto et al. 2019).

Phytochemicals in methanol leaf extract of the present study was highly antagonistic to free radicals and selected bacterial strains. Hydrophilic hydroxyl and amine groups of phenols, flavonoids and alkaloids aids in binding and penetration through the bacterial cell membrane (Sefa et al. 2020). The variation in the antibacterial activity among the extracts might be due to difference in qualitative phytochemicals or morphological variations of test pathogens (Giraldes et al. 2020). *A. marina* has showed the bactericidal activity against *P.aeruginosa, E.coli, S. aureus* (Okla et al. 2021), *R.apiculata* and *R.mucronata* against *A.hydrophila, V.harveyi, S.agalactiae* (Vittaya et al. 2022). MIC is the minimal concentration of the antipathogenic drug that arrest the visible pathogen growth (Kowalska-Krochmal and Dudek-Wicher 2021). Mangroves are potent inhibitors of bacterial pathogens, methanol leaf extract of *R.apiculata* showed significant MIC of 12.5 mg/ml and 6.25 mg/ml against *E.coli* and *S.agalactiae* (Laith 2021), MIC of methanol root extract of *B.gymnorrhiza* against *P.aeruginosa* and *S.enteric* was 48.27 µg/ml and 13.41 µg/ml (Acharya et al. 2020). Saad et al. (2011) reported the MIC of ethyl acetate, n-hexane, methanol leaf extracts of *L. littorea* against *S.aureus, B. cereus* and *E.coli* which ranged from 0.04 µg/ml to 1.11 µg/ml.

In the present observation, DPPH and FRAP assays depicted highest radical scavenging ability and the least IC_{50} in the methanol extract. Free radicals are usually produced in the body, during stress or diseased conditions and are scavenged by the antioxidants in the body (Beulah et al. 2022). (Sasidharan et al. 2011) conducted the studies on antioxidant potency of four mangrove plants, *R.mucronata, R. apiculata, A. officinalis* and *A. marina.* DPPH and FRAP results of the current study are in compliment with the *R.mucronata* leaf extracts (Beulah et al. 2022). Root and leaf extracts of

Table 4 GC–MS characterization of band AM2, *A.ilicifolius* methanol extract

S.no	Name of the compound	Synonym	Molecular Formula	Molecular mass	RT	Peak area %
1.	2-Propanethiol	Isopropanethiol, isopropylthiol, 2-Mercaptopropane, 2-propyl mercaptan	C_3H_8S	76.034	43.999	68.00
2.	Trimethylphosphine	Phosphine, trimethyl, trimethyl phosphorous	C_3H_9P	76.04	76.799	3.75
3.	Pentanoyl chloride	Valeryl chloride, valeroyl chloride, n-valeroyl chloride	$C_5H_9C_{lO}$	120.03	29.999	0.56
4.	Dimethylhydroxymethylphosphine	(Dimethylphosphino)methanol	C_3H_9OP	92.04	46.999	0.51
5.	Propanedinitrile, ethylidene-	Hydroxymethyl-dimethylphosphine	$C_5H_4N_2$	92.037	52.446	0.63
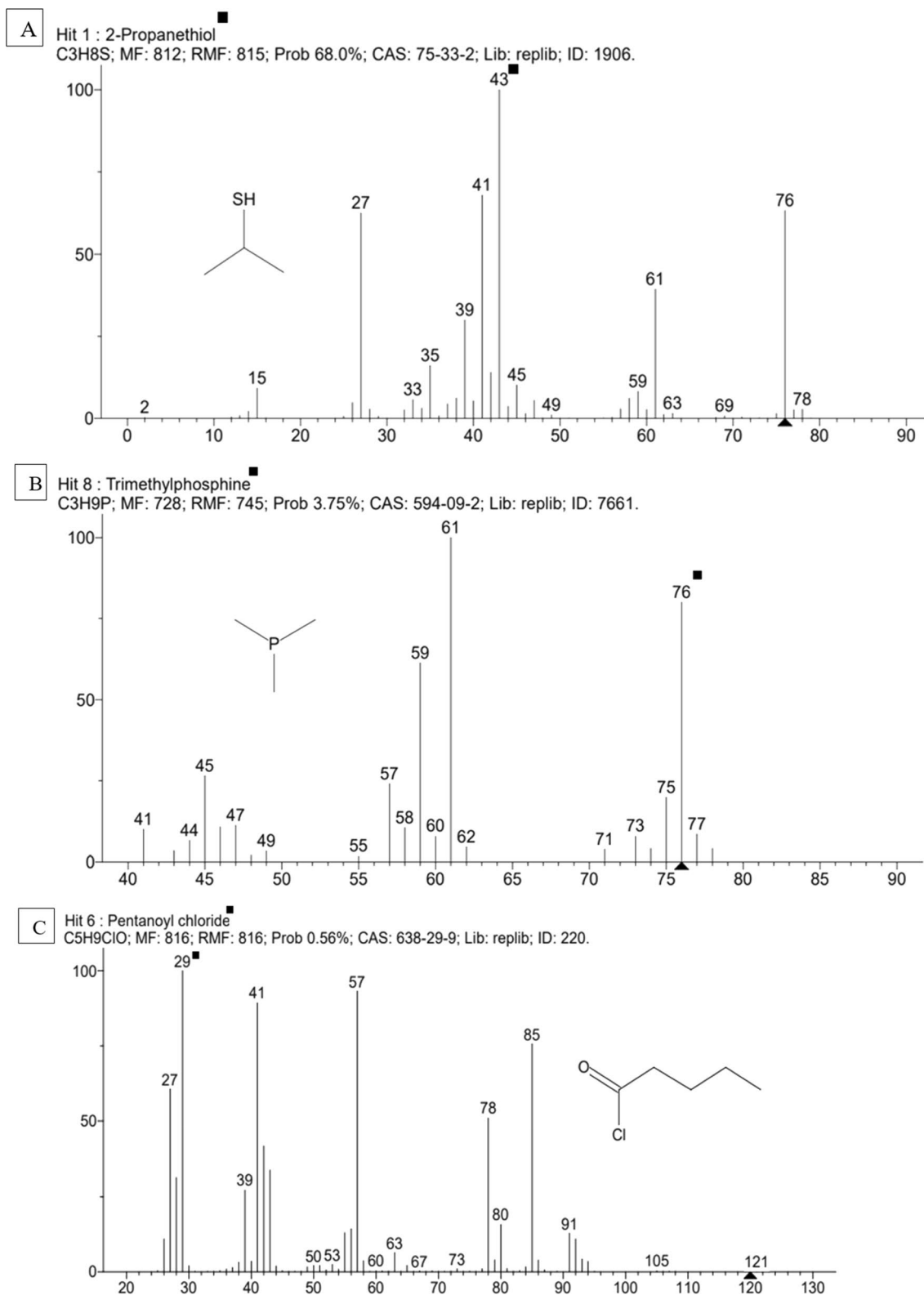
Fig. 5 A–E GC–MS chromatogram of band AM2, *A.ilicifolius* methanol extract
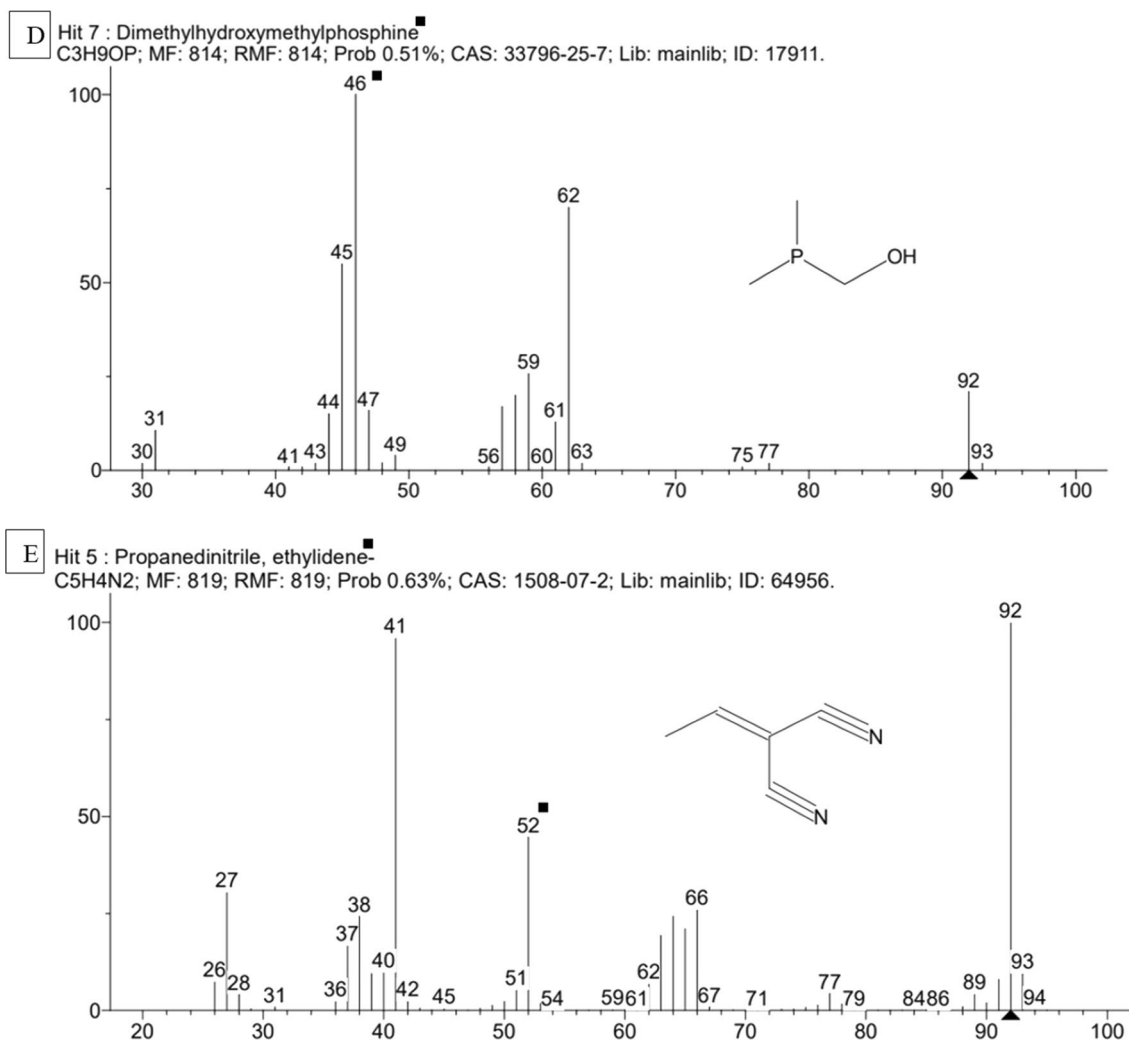
Fig. 5 continued
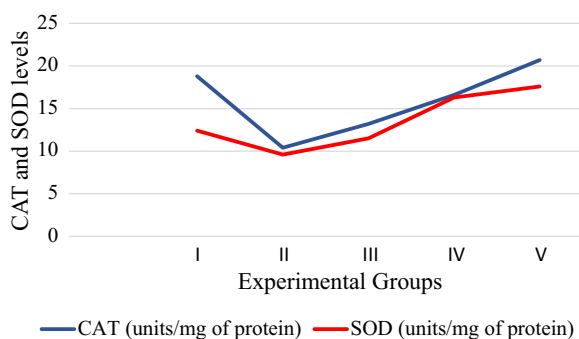
Fig. 6 Levels of antioxidant enzymes CAT and SOD in experimental groups

A.ilicifolius act as potent antioxidants against free radicals (Firdaus et al. 2013).

Crude extracts are complex of phytocompounds from which impurities or unnecessary compounds must be dismissed to know the exact compound responsible for the antimicrobial activity (Sasidharan et al. 2011). Fraction A of column and band AM2 of TLC has elevated antibacterial and antioxidant activity than the crude methanol extract. This was in par with the studies of (Moovendhan et al. 2015) in *A.marina,* (Beulah et al. 2021) in *S.maritima* and (Divya et al. 2022) in *E.agallocha*. The compounds that are responsible for the antimicrobial activity are characterized and structurally elucidated by GC–MS (Konappa et al. 2020). 2-propanethiol is strong antioxidant and anti- bacterial agent (Demirkol et al. 2004), trimethylphosphine and dimethylhydroxymethylphosphine are the antibacterial agents (Wu et al. 2019), Pentanoyl chloride is an acylated

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compound that enhances the antimicrobial and antioxidant activity (Avitabile et al. 2018), propanedinitrile ethylidene act as antimicrobial agent (Puthran et al. 2019).

Biotic and abiotic stress favours the prevalence of *A.hydrophila* infection in fish. In the present study, resulted pathological symptoms in the *L.rohita* fingerlings of infected groups were in coherence with the *Aeromonas* infection in *C. carpio, C. catla* and *L.rohita* (Saharia et al. 2018). It is evident from the in vivo studies that the increased survival in groups IV and V reflecting the antibacterial efficiency of the some phytocompounds. After first day of the treatment with the leaf extracts, groups IV and V has not showed any notable recovery changes, but on day 2 of the treatment, the feeding and swimming pattern were normalised and from day 3 with increase in the duration of the treatment the fingerlings slowly recovered from the gill necrosis, haemorrhages, septicaemia, bulged eyes, fin abrasion and abdominal dropsy. However, the observed mortality in the plant extract treated groups (Group IV and V) might be due to the stress imposed by the bacterial infection and more susceptibility of the fingerlings to the infection. Similarly, *R.mucronata* reported positive results in therapy against *Vibrio harveyi* in Nile tilapia (Mulyani et al. 2020). (Limbago et al. 2021) biologically proved the antibacterial potency of mangrove plants *Sonneratia alba, A. marina, A.officinalis,* and *B.cylindrica* against *Salmonella arizonae* in *Carassius auratus.*

CAT and SOD in the hepatic tissues act as first line of defence and controlling the levels of ROS (Abhijith et al 2016). In the current study, the antioxidant potency of phytocompounds was mirrored in the enhanced levels of CAT and SOD in the fingerlings of groups IV and V over group I, II and III, implying to the increased or decreased liver functioning that might be due to the variation in the free radical production (Rao 2006).

Phytotherapeutics is an efficient eco-friendly treatment for diseases without disturbing the environmental sustainability. Mangrove extracts can be an impressive natural approaches for the therapy of fish diseases in the place of antibiotics or chemical drugs as they can subsidise drug resistance and residual accumulation in fish and consumer. The present in vitro and in vivo studies proved and enhanced the therapeutic knowledge and application of phytocompounds as potent enough to act as antibacterial and antioxidant agents.

Abbreviations

TPC	Total phenol content
TFC	Total flavonoid content
DPPH	α-Diphenyl-β-picrylhydrazyl
FRAP	Ferric reducing antioxidant power
CAT	Catalase
SOD	Superoxide dismutase
MHA	Mueller Hinton Agar media
MIC	Minimum inhibitory concentration

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13568-023-01595-y.

Additional file 1: Table S1. Antibacterial activity of crude *A. ilicifolius* extracts. **Table S2.** Antibiotic, crude and purified extract treated fingerlings and % survival. **Table S3.** Morphological and Biochemical confirmatory tests for *A. hydrophila*.

Declarations

Ethics approval and consent to participate
The fish fingerlings were collected from local hatchery of Andhra Pradesh. Animal ethical care guidelines were followed for the experimental fishes in the study. As per CPCSEA instruction's protocol, approval for experimentation on fishes is not required.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interest with respect to the work described in this manuscript.

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Publisher's Note

Phytochemical Profiling of Some Important Indigenous Plants

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Abstract:
The aim of the present study was to investigate the phytochemical constituents present in some of the indigenous plants of Hyderabad, Telangana region. The plants included- Clitoriaternatea, Costusigneus, Menispermumcandenese, Moringaoleifera, Nycanthes arbortristis, Ocimum sanctum, Cymbopogoncitratus and Phyllanthusniruri. Leaf extracts were prepared from these plants employing water and methanol as solvents for analysing the presence of various phytochemicals. The results showed presence of a wide range of phytochemicals like flavonoids, saponins, quinones, terpenoids, cardiac glycosides, phenols, tannins and steroids in various aqueous and methanolic test plant extracts.

KEYWORDS: Phytochemicals, aqueous extract, methanolic extract, phytochemical screening.

Introduction

Plants are photosynthetic eukaryotes of the kingdom Plantae that contribute significantly to our economy due to their biomedical importance. They are biochemical factories producing an array of chemically versatile compounds, including vitamins, minerals, fibre, essential oils, and phytonutrients, or phytochemicals. Phytochemicals are non-nutritive and non-essential chemicals that can be defined as bioactive nutrient plant chemicals present in different fruits, vegetables, grains, and other plant foods and having potential health benefits (Liu, 2004; Akuru & Amadi, 2018). Several ethnic and botanical groups have documented the presence of several bioactive compounds in different plant parts such as leaves, flowers, bark, seeds, fruits, stems, and roots (Prabhu et al., 2021). Due to the biomedical significance of these metabolites, thrust areas of botany, phytochemistry, and pharmacology are focusing on preliminary phytochemical screening of plants and their

respective phytochemicals. They impart significant physiological effects in the human body by acting as antioxidants, stimulating enzymes, interfering with DNA replication, destroying bacteria, and seeming to reduce the onset of chronic diseases such as cancer and heart diseases (Scarpa & Ninfali, 2015; Komici,2020).

In Ayurveda, several plant species have been evaluated for their therapeutic potential, leading to the isolation of the lead compounds and their scientific exploration for their medicinal properties and biotechnological applications. Plants have been researched for their therapeutic properties: *Clitoria ternatea has* been reported to be a memory enhancer, nootropic, antistress, anxiolytic, antidepressant, anticonvulsant, tranquilizing, and sedative agent (Mukherjee et al., 2008); *Costus igneus* has proven pharmacological activities like hypolipidemic, diuretic, antioxidant, anti-microbial, and anti-cancerous (Hegde et al., 2014); *Menispermum candenese* has been reported to be effective for the treatment of tonsillitis, diarrhea, and gastroenteritis, (Sugimoto, 1999); *Moringa oleifera* is reported to be anti-inflammatory, antimicrobial, antioxidant, anticancer, cardiovascular, hepatoprotective, anti-ulcer, diuretic, antiurolithiatic, and antihelmintic (Fozia et al., 2012). ; Traditionally, whole plants and different parts of *Nycanthes arbortristis* have been used as an herbal remedy for treating sciatica, arthritis, malaria, enlargement of the spleen, and as a blood purifier (Tripathi and Srivastava, 2021). *Ocimum sanctum* exhibits several physiological actions, including anxiolytic and anti-depressant properties, broad-spectrum antimicrobial activity, etc. (Cohen, 2014); *Cymbopogon citratus is* known for its essential oil and antimicrobial, anti-inflammatory, and sedative properties (Gomes et al., 2017);
The present research work is a comparative analysis of phytochemicals present in some of the locally available plants. The test plants might possess unique phytonutrients, which may lead to the discovery and development of phytochemicals as innovative and novel therapeutic tools with improved medicinal efficacy.

Materials and methods

Sample collection and authentication: Fresh plants were collected from naturally populated area in and around Hyderabad, Telangana in the month of October, 2019. The authentication of plant was done by Botanist, Dr. Mir Zahoor Gul, Botanist, Osmania University, the collected plants were initially washed thrice with tap water and finally once with distilled water. Excess water was drained by damping the plants on filter paper.

Preparation of plant extracts: Fresh samples (10g) each of all the eight plant leaves were extracted with 100ml of water and solvent such as methanol. The solutions were later filtered through Whatman No.1 filter paper and the filtrate were collected (crude extracts) and were evaporated (at 40ºC) with the help of heating mantle (Kumar and Thampi, 2015).

Phytochemical Screening- Plant extracts were screened for various phytochemical constituents using - flavonoids, saponins, quinones, terpenoids, cardiac glycosides, phenols, tannins, steroids, carbohydrates and proteins in various aqueous and methanolic test plant extracts using standard protocols and methods (Mozhiyarasi and Anuradha, 2016).

Results

The results of the present study indicated the presence of various phytochemicals in the water and methanolic extracts of eight plants selected for the investigation. The plants included *Clitoria ternatea, Costus igneus, Menispermum candenese, Moringa oleifera*, *Nycanthes arbortristis, Ocimum sanctum, Cymbopogon citratus* and *Phyllanthus niruri.* The present investigation vividly indicated the presence of various phytochemical compounds, *viz.*, flavonoids, saponins, quinones, terpenoids, cardiac glycosides, phenols, tannins, and steroids, as determined by carrying out various standard phytochemical tests. Results in **Table 1** show the colors obtained for positive reactions for all the phytochemical tests. **Table 2** depicts the results of phytochemical screening of water (aqueous) extract of leaves of test plants, whereas **Table 3** depicts the results of phytochemical screening of methanolic extract of leaves of test plants. A marked variation in phytochemicals was obtained when comparing all the test plants belonging to different families.

Discussion

Phytochemical screening of plants offers an important tool for identifying novel sources of therapeutics that could later have industrial applications. The present study reports a comparative analysis of phytochemicals from plants belonging to diverse families, viz., Fabaceae, Costaceae, Menispermaceae, Moringaceae,Oleaceae, Lamiaceae, Poaceae, and Phyllanthaceae. We selected different plants belonging to different families in order to compare the presence or absence of various biologically important phytochemicals in their water (aqueous) and methanolic extracts from leaves. In the present study, water (aqueous) and methanolic extracts of eight plants— *Clitoria ternatea, Costus igneus, Menispermum candenese, Moringa oleifera*, *Nycanthes arbortristis, Ocimum*

sanctum, Cymbopogon citratus and *Phyllanthus niruri*—were used for investigating their qualitative phytochemical composition. Earlier researchers have also reported such studies, but we have tried to provide a comparative analysis of different families based on the presence or absence of phytochemicals in their aqueous and methanolic extracts. Phytochemical screening, or panelling, is a preliminary step towards developing new drugs. Phytochemicals like flavonoids, saponins, quinones, terpenoids, cardiac glycosides, phenols, tannins, and steroids possess important medicinal values, as has been documented earlier by various researchers. Flavonoids possess various pharmacological effects, like anti-oxidative, anti-inflammatory, anti-carcinogenic, and neuroprotective effects. Saponins are organic chemicals that have a foamy quality and have industrial applications for making detergents, soaps, etc. Terpenoids possess pharmacological bioactivity and are of great interest to medicinal chemists. Cardiac glycosides are a class of organic compounds that possess cardioprotective activities. Phenols possess antioxidant, structural, attractant, signalling, and protective functions. Steroids are biologically active compounds possessing anti-inflammatory activities (Liu, 2004; Dillard and German, 2000; Babenko et al., 2019; Scarpa & Ninfali, 2015). The results obtained in this study are in agreement with those reported by earlier phytochemists (Laksmi et al., 2015; Karmakar & Fehim, 2018; Babenko et al., 2019; Verma et al., 2019; Muthukumar et al., 2019; Deorankar et al., 2020; Komici et al., 2020; Nishu & Chandrawati, 2020; Prabhu et al., 2021).

Conclusion

A rich source of potential new medicines, phytochemicals constitute a class of substances with significant biological and physiological importance. As prospective alternatives to allopathic medications, intensive research on these bioactive substances is urgently needed. Their effectiveness as medicines has to be further investigated. The pharmaceutical industry could be able to mix leaf extracts from several plants into a consortium of extracts with all possible medicinal characteristics with the use of a comparative study of these phytochemicals. A future study may be done along this line.

Acknowledgement

Table 1: Positive results of phytochemical screening of test plants with colors produced after the test reaction.

S. No.	Phytochemicals	Observation
1.	**Flavonoids**	Positive- (green brown)
2.	**Saponins**	Positive- (frothing)
3.	**Quinones**	Positive- (green)
4.	**Terpenoids**	Positive- (reddish brown)
5.	**Cardiac Glycosides**	Positive- (reddish brown ring)
6.	**Phenols**	Positive- (greenish yellow)
7.	**Tannins**	Positive- (brownish green)
8.	**Steroids**	Positive- (wine red colour)

Table 2: Phytochemical screening of water (aqueous) extract of leaves of test plants

SN	Phytochemicals	Aqueous extract of leaves-							
		Ct	*Ci*	*Mc*	*Mo*	*Na*	*Os*	*Cc*	*Pn*
1.	**Flavonoids**	-	+	-	+	+	-	+	+

		Ct	Ci	Mc	Mo	Na	Os	Cc	Pn
2.	**Saponins**	+	-	-	+	+	+	+	+
3.	**Quinone**	+	-		-	-	+	+	+
4.	**Terpenoids**	+	-	+	+	+	-	+	+
5.	**Cardiac glycosides**	-	+	+	+	+	+		
6.	**Phenols**	+	+	+	ND	ND	+	+	+
7.	**Tannin**	-	+	-	+	+	ND	+	+
8.	**Steroids**	+	-	-	ND	ND	+	+	+

Plants- *Ct-Clitoria ternatea, Ci-Costus igneus, Mc-Menispermum candenese, Mo-Moringa oleifera, Na-Nycanthes arbortristis, Os-Ocimum sanctum,Cc-Cymbopogon citratus* and *Pn-Phyllanthus niruri.*
+ = Indicates presence of a phytochemical compound.
- = Indicates absence of a phytochemical compound.
ND-Not Determined.

Table 3: Phytochemical screening of methanolic extract of leaves of test plants

S.No.	Phytochemicals	Methanol extract of leaves-							
		Ct	*Ci*	*Mc*	*Mo*	*Na*	*Os*	*Cc*	*Pn*
1.	**Flavonoids**	-	+	-	+	+	+	+	+
2.	**Saponins**	+	+	+	-	-	-	+	+
3.	**Quinone**	+	+	+	+	+	+	+	+
4.	**Terpenoids**	+	+	+	+	+	+	+	+
5.	**Cardiac glycosides**	+	+	+	-	-	+	ND	ND
6.	**Phenols**	-	+	+	ND	ND	+	+	+
7.	**Tannin**	+	+	-	+	+	ND	+	+
8.	**Steroids**	+	+	+	ND	ND	+	+	+

Plants- *Ct-Clitoria ternatea, Ci-Costus igneus, Mc-Menispermum candenese, Mo-Moringa oleifera, Na-Nycanthes arbortristis, Os-Ocimum sanctum, Cc-Cymbopogon citratus* and *Pn-Phyllanthus niruri.*
+ = Indicates presence of a phytochemical compound.
- = Indicates absence of a phytochemical compound.
ND-Not Determined.

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3D MHD Radiation Flow of Unsteady Casson Fluid with Viscous Dissipation Effect

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Abstract

A numerical evaluation of the crucial physical properties of a 3D unsteady MHD flow along a stretching sheet for a Casson fluid in the presence of radiation and viscous dissipation has been carried out. Meanwhile, by applying similarity transformations, the nonlinear partial differential equations (PDEs) are transformed into a system of ordinary differential equations (ODEs). Furthermore, in the numerical solution of nonlinear ODEs, the shooting method along with Adams Moulton method of order four has been used. The obtained numerical results are computed with the help of FORTRAN. The tables and graphs describe the numerical results for different physical parameters which affect the velocity and temperature profiles.

Keywords: Magnetohydrodynamic, thermal radiation, Casson fluid, viscous dissipation, Adams-Moulton method.

1. Introduction

During the past few decades, the boundary layer problems related to a stretching surface have attracted extensive attention of researchers, because the number of applications related to this area is found in engineering and industrial manufacturing processes. Actually, the boundary layer has a meaningful concept in physics and fluid mechanics, which is introduced as the layer of the fluid in the region of a bounded area where the effects of viscosity are powerful. Moreover, it is also a region in the flow field in which the fluid deforms with a relative velocity. Each primary fluid has some basic important properties which play an essential role in its dynamics. The stretching and cooling rates both are significant in the manufacturing process for the effective results of the final product. A speedy change in stretching damages the final product because of sudden solidification, so it is essential to maintain the stretching rate. The 2D flow of an incompressible liquid within the boundary layer along the stretching surface was first presented by Crane [1]. Various researchers have studied the interesting fluid flow along a stretching sheet [2-5].

Magnetohydrodynamics (MHD) is a combination of three words, magneto means magnetic field, hydro means water and dynamics means movements. Meanwhile hydromagnetic flow is

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the analysis of the magnetic properties of an electrically conducting fluid. Plasmas, liquid metals, saltwater, and electrolytes are considered magneto fluids. MHD flow has a wide range of applications in engineering devices such as the design of heat exchanges, blood pumping machines and the MHD electric power generators. The main role of a magnetic parameter in the flow field is to produce a resistive force which maintains the flow and detains the boundary layer separation. A number of researchers investigated the flow models which contain the hydromagnetic effects. On top of that, Pavlov [6] examined the MHD flow of viscous fluids along a stretching sheet. Alfven [7] established the existence of electromagnetic-hydro-dynamic waves. Sarpakaya [8] studied the flow of specific types of fluids in the magnetic field.

The time-dependent flows are considered as unsteady flow. Wang [9] investigated the time dependent flow problems. Furthermore, various researchers considered the impacts of induced magnetic field on the time dependent MHD flow within the boundary layer region [10-12]. Ishak et al. [13] studied the heat transfer of a time dependent flow. The temperature variation between the surrounding and the ambient fluid, produce the radiation.

The complicated behavior of stress-strain can be found in a type of fluids which is called non-Newtonian fluids. Moreover, non-Newtonian fluids have earned considerable attention because a number of applications of these fluids are found in engineering and industry. The Casson fluid is one of the most important non-Newtonian fluids, which is used in metallurgy, food processing etc. Casson [14] introduced the Casson fluid model for the pigment-oil suspensions. Casson fluid exhibits the properties of yield stresses. Whenever the shear stress is greater than the yield stress, the fluid acts like a liquid. Likewise, if shear stress is less than the yield stresses the fluid acts like a solid. In the category of Casson fluids, Jelly, shampoo, toothpaste, ketchup, tomato sauce, honey, soup and juices are founded. Actually, yield stress analysis is important for all complex structured fluids. Dash et al. [15] examined the Casson fluid inside a pipe containing a porous medium Later on Eldabe et al. [16] investigated the hydromagnetic flow of a Casson fluid bounded between two cylinders in a rotating position. Later on, several researchers worked on the free convective electromagnetic flow of Casson fluid in various conditions [17-21]. Maleque [22] investigated the MHD flow of Casson liquid along with a rotating disk. Kataria and Patel [23] considered the ramped wall temperature with heat and mass transfer in the hydromagnetic flow of Casson liquid through a porous medium. The MHD Casson fluid with the effects of Hall, Dufour and thermal radiation was analyzed by Vijayaragavan and Karthikeyan [24]. G. Narender et al. [25] studied the impact of the radiation effects in the presence of heat generation/absorption and magnetic field on the magnetohydrodynamics (MHD) stagnation point flow over a radially stretching sheet using a Casson nanofluid. G. Narender et al. [26] examined the viscous dissipation and thermal radiation effects on the MHD mixed convection stagnation point flow of Maxwell nanofluid over a stretching surface. G. Narender et al. [27] explored the impacts of external magnetic field inclinations and viscous dissipation due to heat generation or absorption parameter on MHD mixed convective flow of Casson nanofluid.

The detailed review work of Parshu and Nankeolyar [28] is explained in this article and extended by considering viscous dissipation. The numerical solution of various parameters has been discussed which impact the skin friction coefficients, Nusselt number, velocity and temperature. Investigation of obtained numerical results is given through tables and graphs.

2. Mathematical Modelling
A 3D time-dependent, magnetohydrodynamic flow of an incompressible Casson fluid along a linearly stretchable surface has been examined. Meanwhile, the surface is along the plane,

which means that $y = 0$ and the fluid confined along the positive direction of $y-$ axis has been considered. Furthermore, the sheet is considered to be stretched along $x-$ axis. The time dependent magnetic field has been assumed to act along y-axis which is normal to the surface of the sheet. The physical model of flow is given below in Figure 1. Here u_w is the stretching sheet velocity along the $x-$direction, the surface temperature is T_w and the disposition temperature is T_∞. The system of equations describing the flow has been given below, which contains the PDEs of continuity equation, momentum, and energy transfer [28].
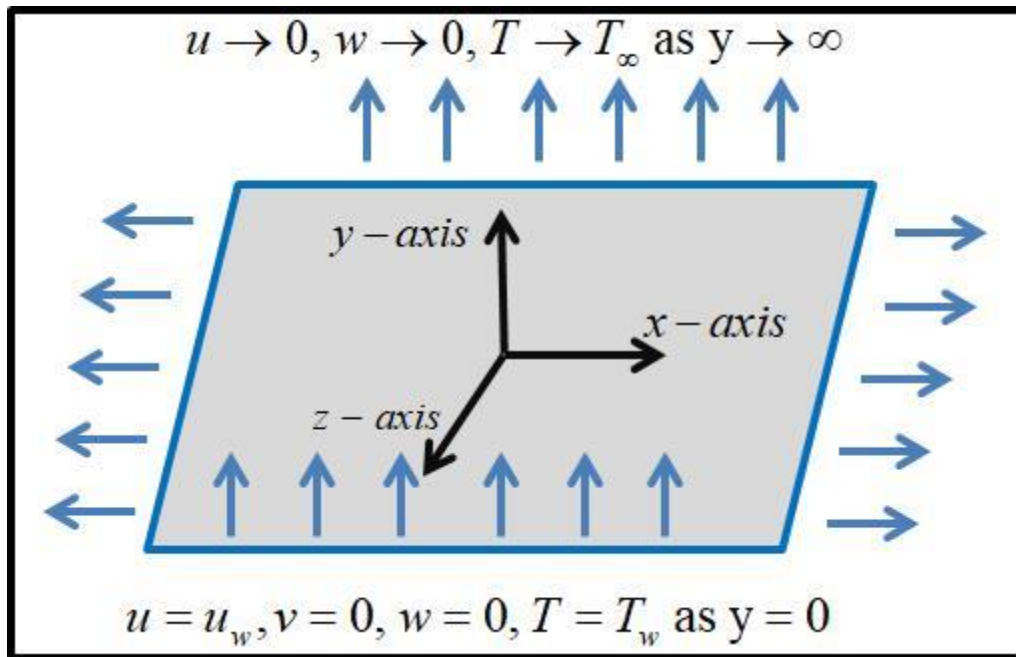
Figure 1: Schematic representation of physical model.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0, \tag{1}$$

$$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial x}u + \frac{\partial u}{\partial y}v + \frac{\partial u}{\partial z}w = v\left(1+\frac{1}{\beta}\right)\left(\frac{\partial^2 u}{\partial y^2}\right) - \frac{\sigma B^2(t)}{\rho\left(1+m^2\right)}(u+mw), \tag{2}$$

$$\frac{\partial w}{\partial t} + \frac{\partial w}{\partial x}u + \frac{\partial w}{\partial y}v + \frac{\partial w}{\partial z}w = v\left(1+\frac{1}{\beta}\right)\left(\frac{\partial^2 w}{\partial y^2}\right) - \frac{\sigma B^2(t)}{\rho\left(1+m^2\right)}(mu-w), \tag{3}$$

$$\frac{\partial T}{\partial t} + \frac{\partial T}{\partial x}u + \frac{\partial T}{\partial y}v + \frac{\partial T}{\partial z}w = -\frac{v}{\rho}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2 + \alpha_m\left(\frac{\partial^2 T}{\partial y^2}\right) - \frac{1}{\left(\rho c_p\right)}\frac{\partial q_r}{\partial y} \tag{4}$$

The associated boundary conditions can be written as:

$$\left.\begin{array}{l} y = 0 : u = U_w(x), v = 0, w = 0, T = T_w, \\ y \to \infty : u \to \infty, w \to \infty, T \to T_\infty. \end{array}\right\} \tag{5}$$

The Casson liquid parameter is denoted by β, the electrical conductivity by σ, density by ρ, the kinematic viscosity by v, Hall current by m, the temperature by T, the thermal diffusivity by $\alpha_m = \dfrac{k}{\rho c_p}$. Furthermore the wall stretching velocity with time dependent by

$u_w(x,t) = \dfrac{ax}{1-\gamma t}$ [28] and the magnetic field with time dependent by $B(t) = B_0 (1-\gamma t)^{-\frac{1}{2}}$, [28]

where a and γ are constants and B_0 the magnetic strength.

The radiative heat flux q_r [28] can be written as

$$q_r = -\frac{4\sigma^*}{3\alpha^*}\frac{\partial T^4}{\partial y} = -\frac{16\sigma^*}{3\alpha^*}T^3 \frac{\partial T}{\partial y} \tag{6}$$

where the Stefan-Boltzmann constant is σ^* and the coefficient of Rosseland mean absorption is α^*. From (6), putting q_r into (4) and after a little simplification, we get

$$\frac{\partial T}{\partial t} + \frac{\partial T}{\partial x}u + \frac{\partial T}{\partial y}v + \frac{\partial T}{\partial z}w = -\frac{v}{\rho}\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)^2 + \frac{\partial}{\partial y}\left(\left(\alpha_m + \frac{16\sigma^* T^3}{3\alpha^* \rho c_p}\right)\frac{\partial T}{\partial y}\right). \tag{7}$$

For the conversion of the mathematical model (2)-(4) into the dimensionless form, the following similarity transformation [28] has been introduced,

$$
\left.
\begin{aligned}
&u = \frac{ax}{1-\gamma t}f'(\eta), \; v = -\sqrt{\frac{av}{1-\gamma t}}f(\eta), \; w = \frac{ax}{1-\gamma t}g(\eta), \\
&\theta(\eta) = \frac{T - T_\infty}{T_f - T_\infty}, \; \eta = y\sqrt{\frac{a}{v(1-\gamma t)}}.
\end{aligned}
\right\} \tag{8}
$$

The final dimensionless form of the governing model, is

$$\left(1+\frac{1}{\beta}\right)f''' + ff'' - (f')^2 - A\left(f' + \frac{\eta}{2}f''\right) - \frac{M}{1+m^2}(f' + mg) = 0, \tag{9}$$

$$\left(1+\frac{1}{\beta}\right)g'' - gf' + fg' - A\left(g + \frac{\eta}{2}g'\right) + \frac{M}{1+m^2}(mf' - g) = 0, \tag{10}$$

$$\left(1+\frac{4}{3N_r}(1+(tr-1)\theta)^3\right)\theta'' - \Pr A\frac{\eta}{2}\theta' + \Pr f\theta' + \Pr\left(1+\frac{1}{\beta}\right)Ec\, f'' +$$

$$\left(\frac{4}{3N_r}(tr-1)(1+(tr-1)\theta)^2\right)(\theta^1)^2 = 0, \tag{11}$$

The associated BCs (5) shown as

$$
\left.
\begin{aligned}
&\eta = 0 : f(\eta) = 0, f'(\eta) = 1, g(\eta) = 0, \theta(\eta) = 1, \\
&\eta \to \infty : f'(\eta) \to 0, g(\eta) \to 0, \theta(\eta) \to 0.
\end{aligned}
\right\} \tag{12}
$$

Different parameters used in (9)-(11) are defined as follow [28]:

$$
\left.
A = \frac{\gamma}{a}, M = \frac{\sigma B_0^2}{\rho a}, \; N_r = \frac{k\alpha^*}{4\sigma^* T_\infty^3}, \Pr = \frac{v}{\alpha_m}, tr = \frac{T_w}{T_\infty}, Ec = \frac{a^2 x^2}{\alpha c_p (T_w - T_\infty)}
\right\} \tag{13}
$$

The skin friction coefficient along $x-$ direction, $z-$ direction and the local Nusselt number are defined as [28]:

$$C_{fx} = \frac{\tau_{wx}}{\rho u_w^2}, \; C_{fz} = \frac{\tau_{wz}}{\rho u_w^2}, \; Nu_x = \frac{xq_w}{k(T_w - T_\infty)} \tag{14}$$

Given below are the formulae for τ_w, q_w and q_m [28].

$$\tau_{wx} = \mu\left(1+\frac{1}{\beta}\right)\left(\frac{\partial u}{\partial y}\right)_{y=0}, \tau_{wz} = \mu\left(1+\frac{1}{\beta}\right)\left(\frac{\partial w}{\partial y}\right)_{y=0}, q_w(x) = -k\left(\frac{\partial T}{\partial y}-\frac{q_r}{k}\right)_{z=0}. \quad (15)$$

The transformation of the above formulae into the dimensionless form has been carried out as:

$$\left.\begin{aligned}
C_{fx}\sqrt{\mathrm{Re}_x} &= \left(1+\frac{1}{\beta}\right)f''(0), C_{fz}\sqrt{\mathrm{Re}_x} = \left(1+\frac{1}{\beta}\right)g'(0),\\
\frac{Nu_x}{\sqrt{\mathrm{Re}_x}} &= -\left[1+\frac{4}{3N_r}\left(1+(t-1)\theta(0)\right)^3\right]\theta'(0).
\end{aligned}\right\} \quad (16)$$

where, τ_{wx} and τ_{wz} denotes the shear stress components, q_w by the heat transfer rate and $\mathrm{Re}_x = \dfrac{x\,u_w}{v}$ elucidates the local Reynolds number.

3. Method of Solution

For the solution of ODEs (9)-(11), the shooting method has been used. The dimensionless equations (9) and (10) are coupled in f and g. These two equations will be solved separately by the shooting method. Later on, the solution of (9) and (10) will be used in (11) as a known input. The missing initial conditions (ICs) $f''(0)$ and $g'(0)$ are denoted by r and s. For further improvement of the missing conditions, Newton's method will be used. Furthermore, the following notations have been incorporated.

$$\left.\begin{aligned}
&f = h_1, f' = h_2, f'' = h_3, g = h_4, g' = h_5,\\
&\frac{\partial f}{\partial r} = h_6, \frac{\partial f'}{\partial r} = h_7, \frac{\partial f''}{\partial r} = h_8, \frac{\partial g}{\partial r} = h_9, \frac{\partial g'}{\partial r} = h_{10},\\
&\frac{\partial f}{\partial s} = h_{11}, \frac{\partial f'}{\partial s} = h_{12}, \frac{\partial f''}{\partial s} = h_{13}, \frac{\partial g}{\partial s} = h_{14}, \frac{\partial g'}{\partial s} = h_{15}.
\end{aligned}\right\} \quad (17)$$

The above mathematical models (9)-(10), now be listed in the form of the following first order coupled ODEs.

$$h_1' = h_2, \qquad\qquad\qquad\qquad\qquad\qquad h_1(0) = 0,$$

$$h_2' = h_3, \qquad\qquad\qquad\qquad\qquad\qquad h_2(0) = 1,$$

$$h_3' = \frac{\beta}{1+\beta}\left[A\left(h_2 + \frac{\eta}{2} h_3 \right) - h_1 h_3 + h_2^2 + \frac{M}{1+m^2}(h_2 + m h_4) \right], \qquad h_3(0) = r,$$

$$h_4' = h_5, \qquad\qquad\qquad\qquad\qquad\qquad h_4(0) = 0,$$

$$h_5' = \frac{\beta}{1+\beta}\left[A\left(h_4 + \frac{\eta}{2} h_5 \right) + h_4 h_2 - h_1 h_5 - \frac{M}{1+m^2}(m h_2 - h_4) \right], \qquad h_5(0) = s,$$

$$h_6' = h_7, \qquad\qquad\qquad\qquad\qquad\qquad h_6(0) = 0,$$

$$h_7' = h_8, \qquad\qquad\qquad\qquad\qquad\qquad h_7(0) = 0,$$

$$h_8' = \frac{\beta}{1+\beta}\left[A\left(h_7 + \frac{\eta}{2} h_8 \right) - h_1 h_8 - h_3 h_6 + 2 h_2 h_7 + \frac{M}{1+m^2}(h_7 + m h_9) \right], \qquad h_8(0) = 1,$$

$$h_9' = h_{10}, \qquad\qquad\qquad\qquad\qquad\qquad h_9(0) = 0,$$

$$h_{10}' = \frac{\beta}{1+\beta}\left[A\left(h_9 + \frac{\eta}{2} h_{10} \right) + h_4 h_7 + h_9 h_2 - h_1 h_{10} - h_6 h_5 - \frac{M}{1+m^2}(m h_7 - h_9) \right], \qquad h_{10}(0) = 0,$$

$$h_{11}' = h_{12}, \qquad\qquad\qquad\qquad\qquad\qquad h_{11}(0) = 0,$$

$$h_{12}' = h_{13}, \qquad\qquad\qquad\qquad\qquad\qquad h_{12}(0) = 0,$$

$$h_{13}' = \frac{\beta}{1+\beta}\left[A\left(h_{12} + \frac{\eta}{2} h_{13} \right) - h_1 h_{13} - h_3 h_{11} + 2 h_2 h_{12} + \frac{M}{1+m^2}(h_{12} + m h_{14}) \right], \qquad h_{13}(0) = 0,$$

$$h_{14}' = h_{15}, \qquad\qquad\qquad\qquad\qquad\qquad h_{14}(0) = 0,$$

$$h_{15}' = \frac{\beta}{1+\beta}\left[A\left(h_{14} + \frac{\eta}{2} h_{15} \right) + h_4 h_{12} + h_{14} h_2 - h_1 h_{15} - h_{11} h_5 - \frac{M}{1+m^2}(m h_{12} - h_{14}) \right], \; h_{15}(0) = 1,$$

The above IVP will be solved numerically by the Adams-Moulton method. To get the approximate solution, the domain of the problem has been taken as $[0, \eta_\infty]$ instead of $[0, \infty)$, where η_∞ is an appropriate finite positive real number. In the above system of equations, the missing conditions r and s, must be chosen in such a way that

$$h_2(\eta_\infty, r, s)_s = 0, \qquad\qquad h_4(\eta_\infty, r, s)_s = 0 \qquad\qquad\qquad (18)$$

For the improvement of the missing condition, Newton's method has been implemented which is conducted by the following iterative scheme:

$$\begin{bmatrix} r^{(k+1)} \\ s^{(k+1)} \end{bmatrix} = \begin{bmatrix} r^{(k)} \\ s^{(k)} \end{bmatrix} - \left[\begin{bmatrix} h_7 & h_9 \\ h_{11} & h_{14} \end{bmatrix}^{-1} \begin{bmatrix} h_2 \\ h_4 \end{bmatrix} \right]_{\left(r^{(k)}, s^{(k)}, \eta_\infty \right)} \qquad\qquad (19)$$

The following steps are involved for the accomplishment of the shooting method.

(i) Choice of the guesses $r = r^{(0)}$ and $s = s^{(0)}$.

(ii) Choice of a positive small number ε.

If $\max\left\{ |y_2(\eta_\infty) - 0|, |y_4(\eta_\infty) - 0| \right\} < \varepsilon$, the process is terminated, otherwise go to (iii).

(iii) Compute $r^{(k+1)}$ and $s^{(k+1)}$, $k=0,1,2,3,...........,$ by using (19).

(iv) Repeat (i) and (ii).

In a similar manner, the ODE (11) along with the associated BCs can be solved by considering f as a known function.

4. Representation of Graphs and Tables

The physical impacts of significant parameters on the skin friction coefficients and Nusselt number have been explained through graphs and tables. Prashu and Nankeolyar [28] used the spectral Quasilinearization method (SQLM) for the numerical solution of the discussed model. In the present survey, the shooting method along with Adams-Moulton Method has been opted for reproducing the solution of [28]. The results discussed in Table 4.1, reflect the impacts of significant parameters on the skin friction coefficients $-C_{fx}\,\mathrm{Re}^{\frac{1}{2}}$ and $-C_{fz}\,\mathrm{Re}^{\frac{1}{2}}$.

The results are compared with those of Prashu and Nankeolyar [28] showing an excellent agreement. For the rising values of the M, skin friction coefficient increases in both x and z direction. The skin friction coefficient decreases in both x and z direction due to ascending values of the β Casson parameter. Furthermore, the accelerating values of m Hall current decrease the $-C_{fx}\,\mathrm{Re}^{\frac{1}{2}}$ and increase $-C_{fz}\,\mathrm{Re}^{\frac{1}{2}}$. Likewise, by increasing the values of unsteadiness A, there is a marginal increment in the skin friction coefficient along the x axis and a decrement along the z axis.

Table 4.1: Results of the $-C_{fx}\,\mathrm{Re}^{\frac{1}{2}}$ and $-C_{fz}\,\mathrm{Re}^{\frac{1}{2}}$ for various parameters.

M	m	A	β	$-C_{fx}\,\mathrm{Re}^{\frac{1}{2}}$		$-C_{fz}\,\mathrm{Re}^{\frac{1}{2}}$	
				[28]	Present	[28]	Present
6	0.1	0.1	0.3	5.51874456	5.518748000	0.23905696	0.239053200
2				3.63997437	3.640760000	0.12517671	0.124864700
8				6.24973648	6.249738000	0.27988605	0.279885500
	0.5			5.15310039	5.153086000	1.03810463	1.038099000
	1.0			4.47154368	4.471480000	1.50968576	1.509767000
		0.13		5.52749427	5.527499000	0.23866458	0.238661000
		0.15		5.53332180	5.533327000	0.23840377	0.238400300
			0.5	4.59187303	4.591874000	0.19890741	0.198907200
			0.6	4.32925941	4.329258000	0.18753170	0.187531600

In Table 4.2, the effects of the significant parameters on Nusselt number $Nu_x\,\mathrm{Re}^{-\frac{1}{2}}$ have been discussed. The growing pattern is found in the $Nu_x\,\mathrm{Re}^{-\frac{1}{2}}$ due to the accelerating values of m, Prandtl number Pr and temperature ratio tr, while the magnetic parameter M, unsteadiness parameter A and Casson parameter β cause a decrement in the Nusselt number.

Table 4.2: Results of the $Nu_x \, \mathrm{Re}^{-\frac{1}{2}}$ **for various parameters.**

M	m	A	Nr	tr	β	Pr	$Nu_x \, \mathrm{Re}^{-\frac{1}{2}}$	
							[28]	Present
6	0.1	0.1	2	1	0.3	10	2.68073953	2.680741
2							2.85395341	2.853843
8							2.61197510	2.611977
	0.5						2.70970177	2.709705
	1.0						2.76677553	2.766787
		0.13					2.64303470	2.643035
		0.15					2.61732067	2.617321
			4				2.44614512	2.446145
			6				2.35862695	2.358628
				2			3.86324873	3.863249
				3			5.08255834	5.082558
					0.5		2.57918784	2.575941
					0.6		2.54083532	2.537679
						15	3.39809230	3.398094
						20	4.00188854	4.001891

   Figures 4.2 – 4.4 shows the effects of different parameters on the velocity and temperature respectively. Figure 4.2 shows the decreasing behavior of velocity along the x direction, due to rising values of the β and the M. Actually, the β reveals the properties of yield stress. Stabilization effects are also found by extending the yield stress. The impacts of applied magnetic field give rise to a resistive force in flow field called the Lorentz force. Figure 4.3 reflects that the increasing values of the Casson parameter β and the magnetic field M, the velocity profile along the $z-$axis increases near the boundary surface and then starts reducing away from the boundary surface. The temperature profile accelerates due to rising values of the β and M which is illustrated in Figure 4.4.

   Furthermore, the effects of significant parameters, the Hall Current m and the unsteadiness A on the velocity behaviors and the temperature profile are illustrated in Figures 4.5 – 4.7 when the power of the magnetic field is strong then no one can neglect the effect of Hall current because the utilization of the magnetic field with electrically conducting fluid produces Hall current m. Figures 4.5 (a) and (b) illustrate the effects of the m and the A on the velocity profile along the x direction. By ascending values of m, the velocity profile is also increased, while increasing values of the unsteadiness A, there is a marginal decay in the velocity profile. Figures 4.6 (a) and (b) show the effects of the m and the A on the velocity profile along the z direction. The increasing values of the m, there is a significant rise in the velocity profile, while for the increasing values of the A, there is a marginal decrement in the velocity profile within boundary layer region. Figures 4.7 (a) and (b) show the impact of the m and the A on the temperature. Meanwhile the temperature is a reducing function of the Hall current m and by increasing the values of the unsteadiness A, there is a marginal enhancement in the temperature behavior. By ascending values of the Hall current m, are found to enhance the thickness of the momentum boundary layer. However, by accelerating values of the unsteadiness A, the thermal boundary layer becomes thick.

The influence of the significant parameters on the temperature behavior is shown in Figures 4.8–4.11 respectively. In Figure 4.8, the rising values of radiative parameter Nr, the temperature is reduced because the temperature distribution is inversely proportion to the Nr. In Figure 4.9 shows that the greater values of Prandtl number Pr has shrink the temperature profile. However, Pr is the ratio of the viscous diffusion to the thermal diffusion. Figure 4.10 portrays that the increasing values of temperature ratio tr, the temperature profile shows a growing behavior. Actually, tr is a ratio between temperature behavior at the surface to the temperature behavior beyond the surface. Further, Figure 4.11 is delineated to show the impact of Ec on the temperature field $\theta(\eta)$. This graph exhibits that by enhancing the estimations of Ec, the temperature field $\theta(\eta)$ is also increased.
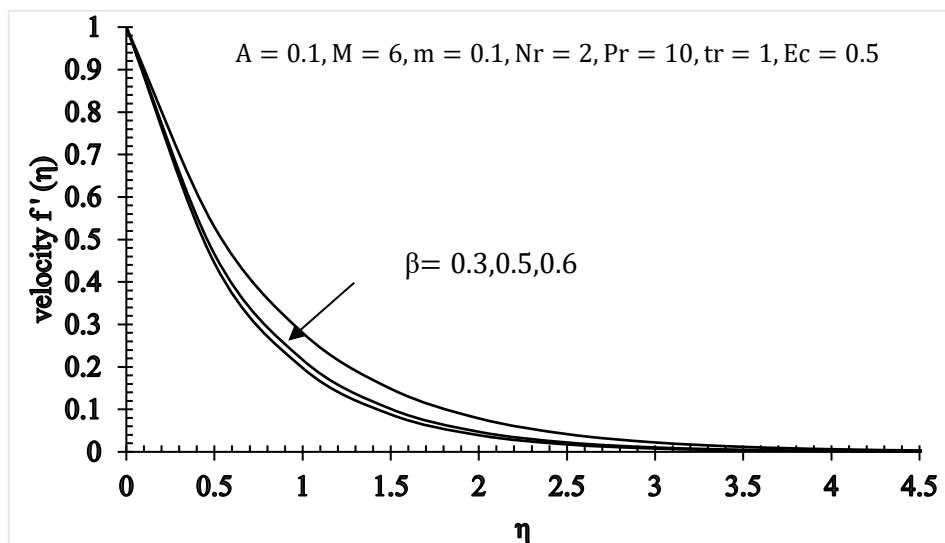
(a)
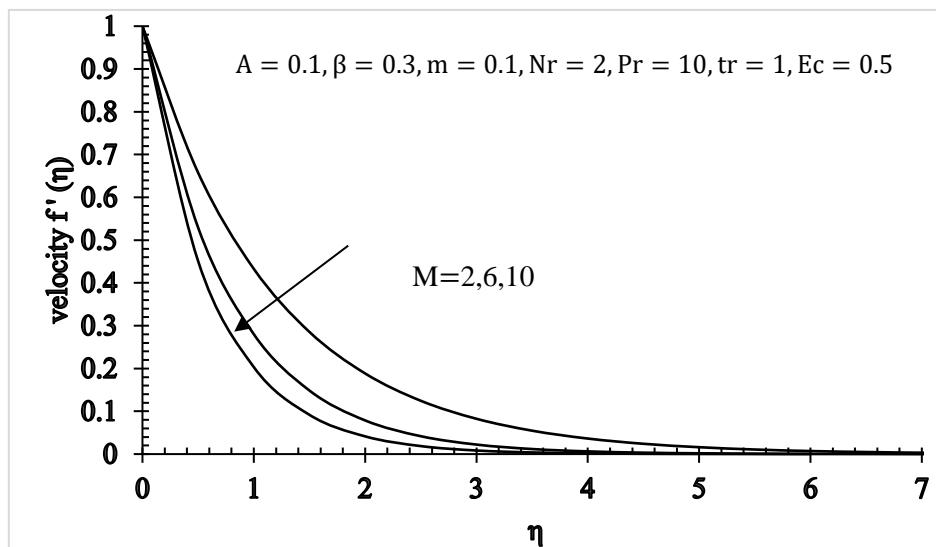
(b)

Figure 4.2: Change in $f''(\eta)$ for rising values of β and M.

(a)

(b)
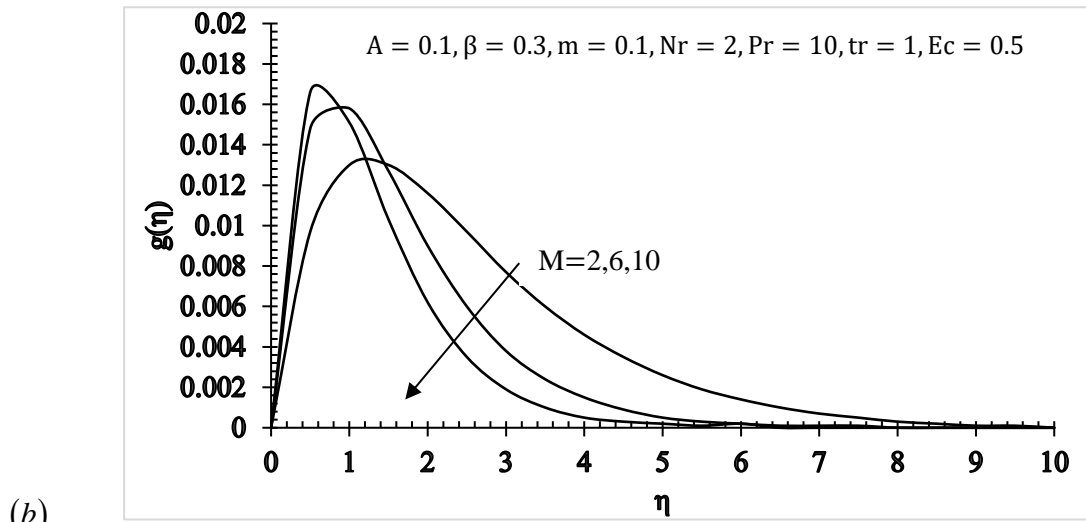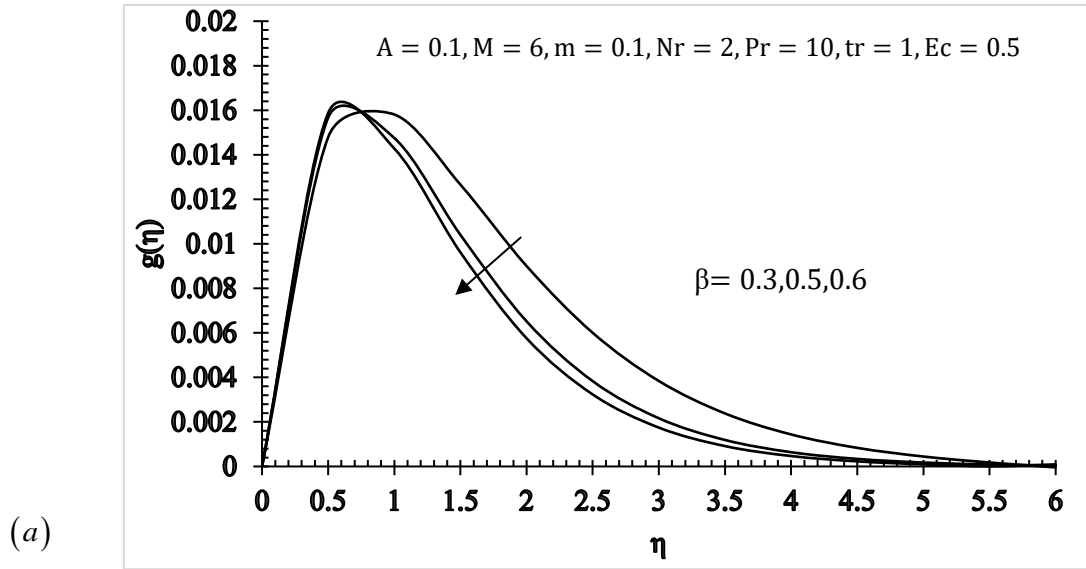
Figure 4.3: Change in $g(\eta)$ for rising values of β and M.

(a)

(b)
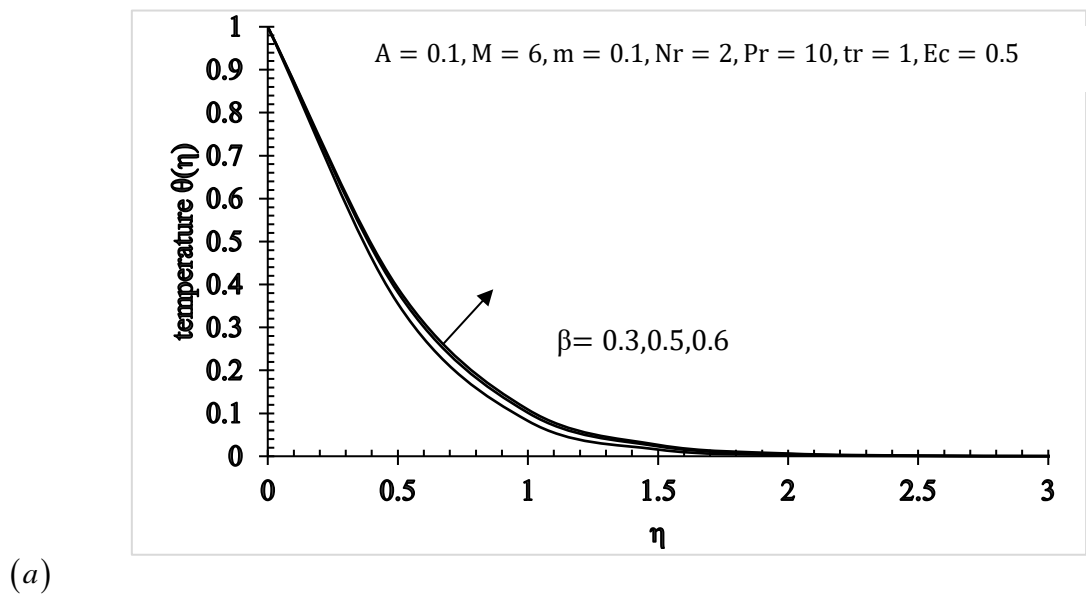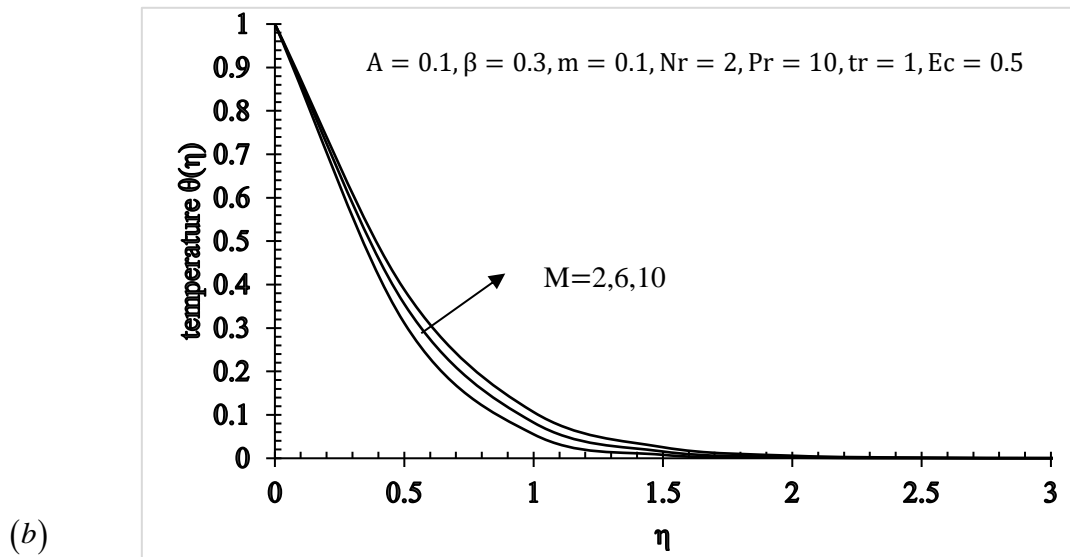
Figure 4.4: Change in $\theta(\eta)$ for rising values of β and M.

(a)

(b)
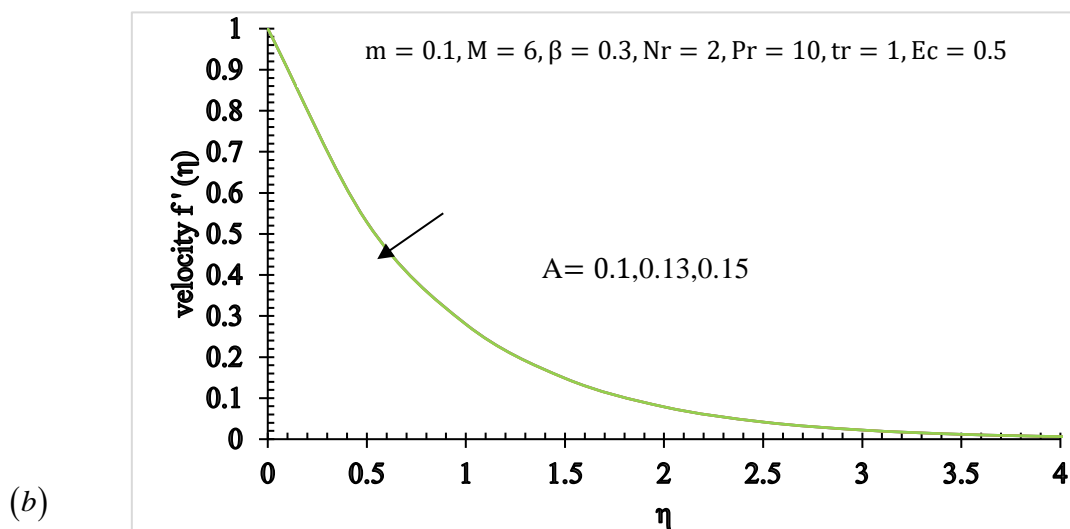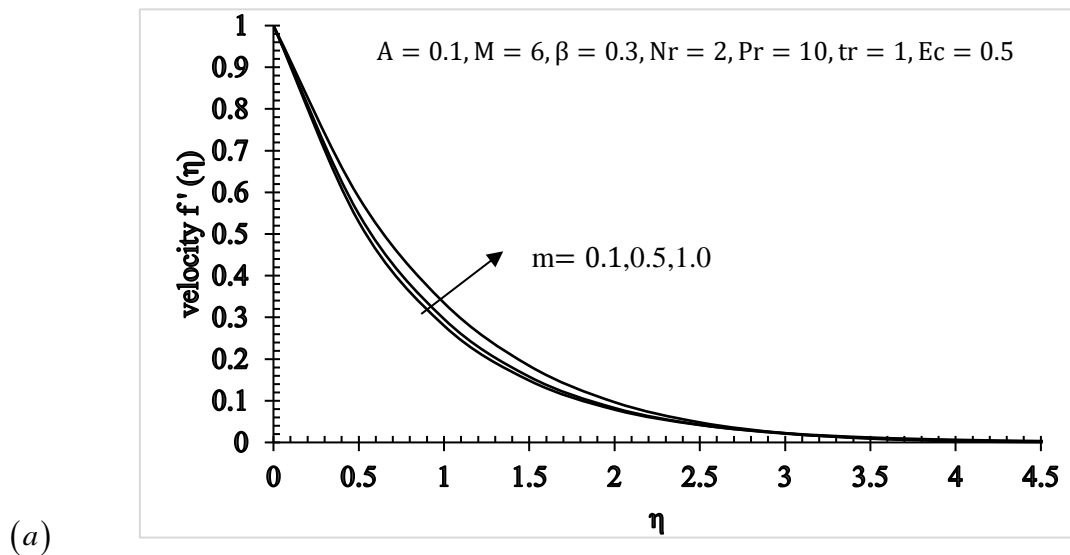
Figure 4.5: Change in $f^{''}(\eta)$ for rising values of m and A.

(a)

(b)
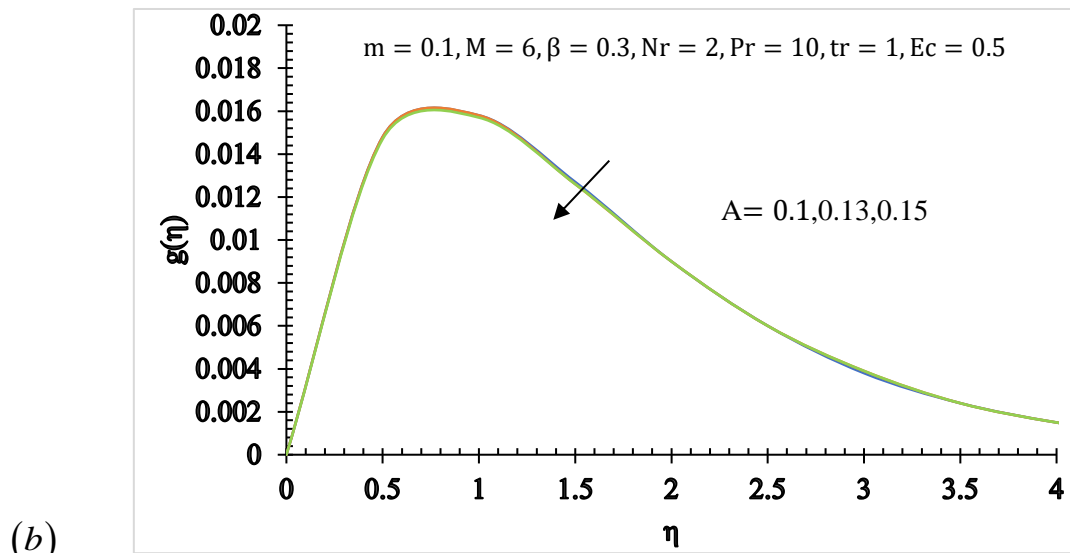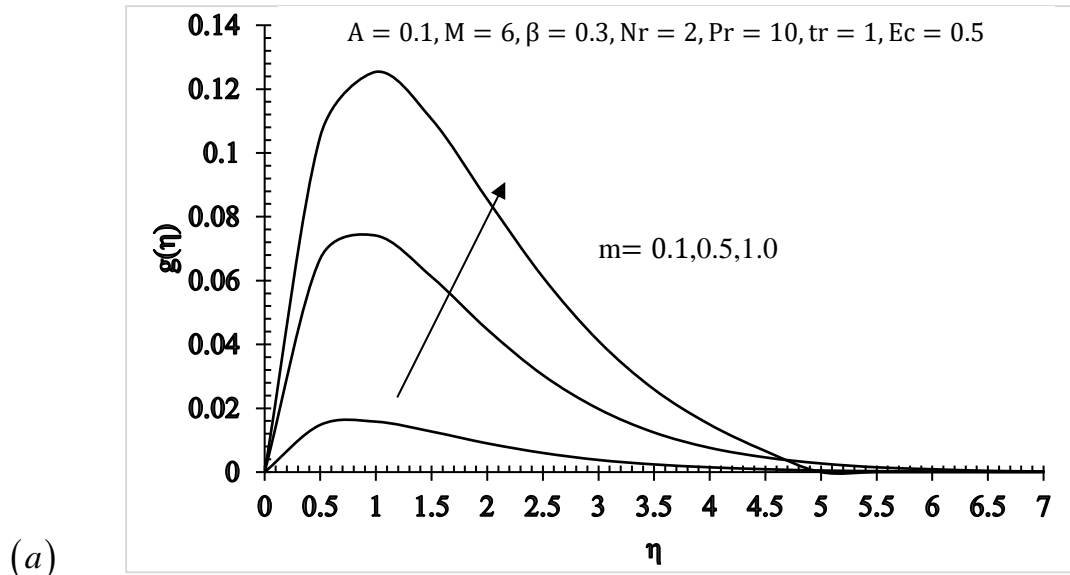
Figure 4.6: Change in $g(\eta)$ for rising values of m and A .

(a)
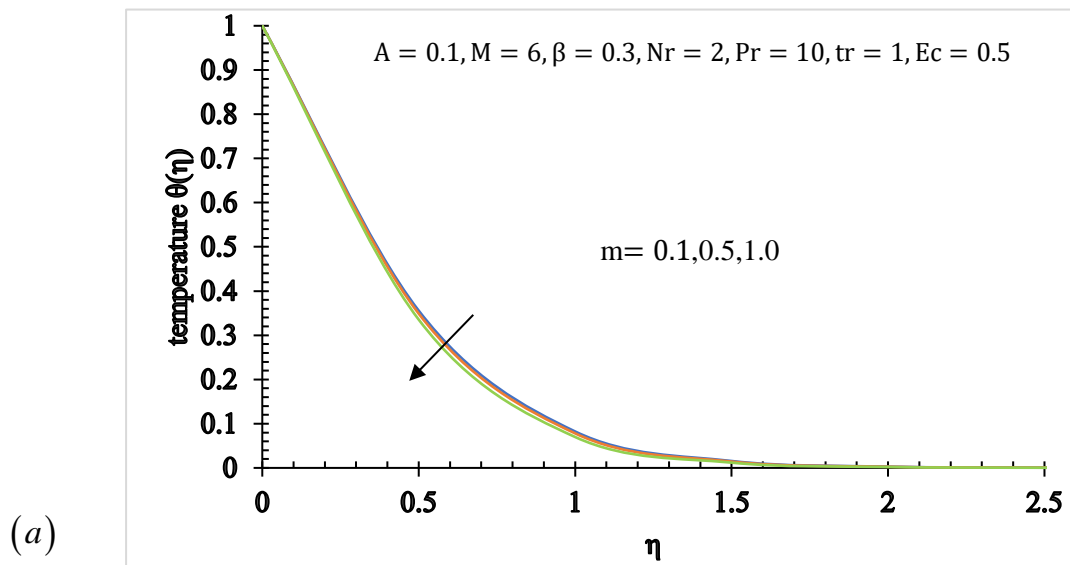
(b)
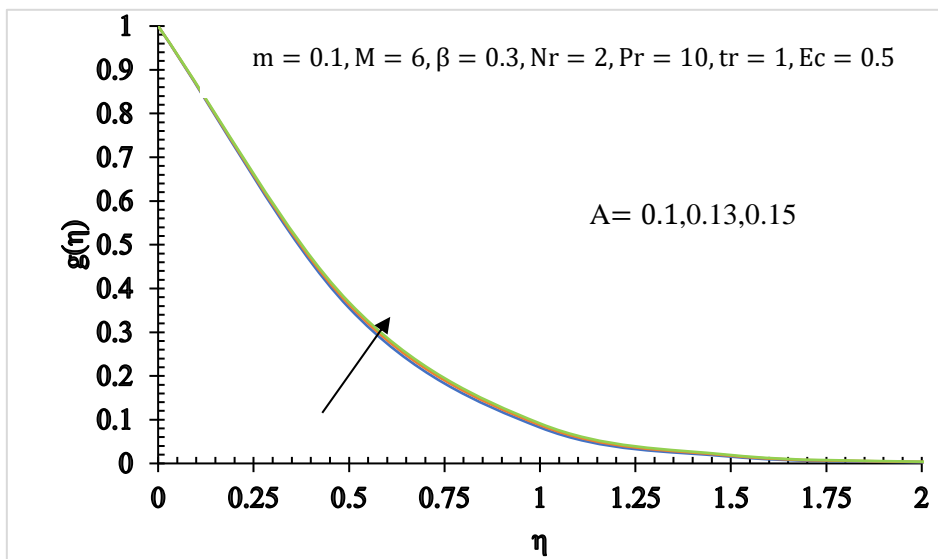
Figure 4.7: Change in $\theta(\eta)$ for rising values of m and A .
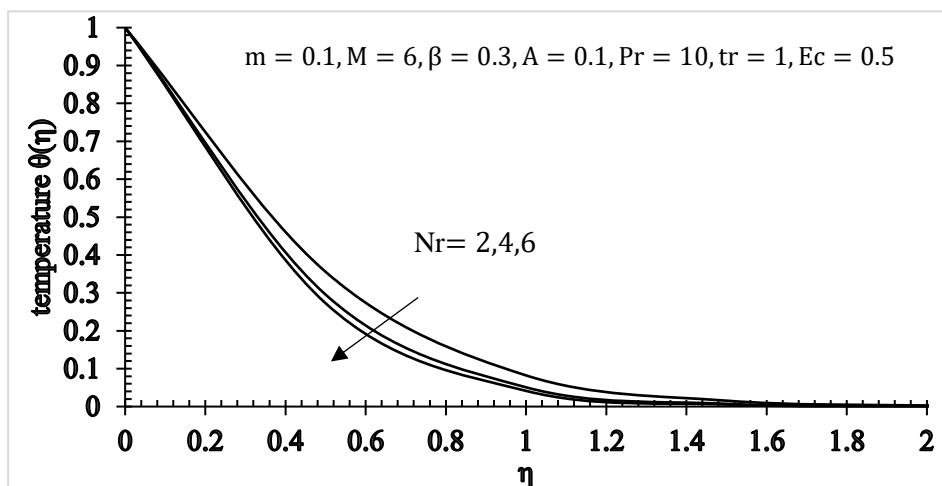
Figure 4.8: Change in $\theta(\eta)$ for ascending values of Nr .
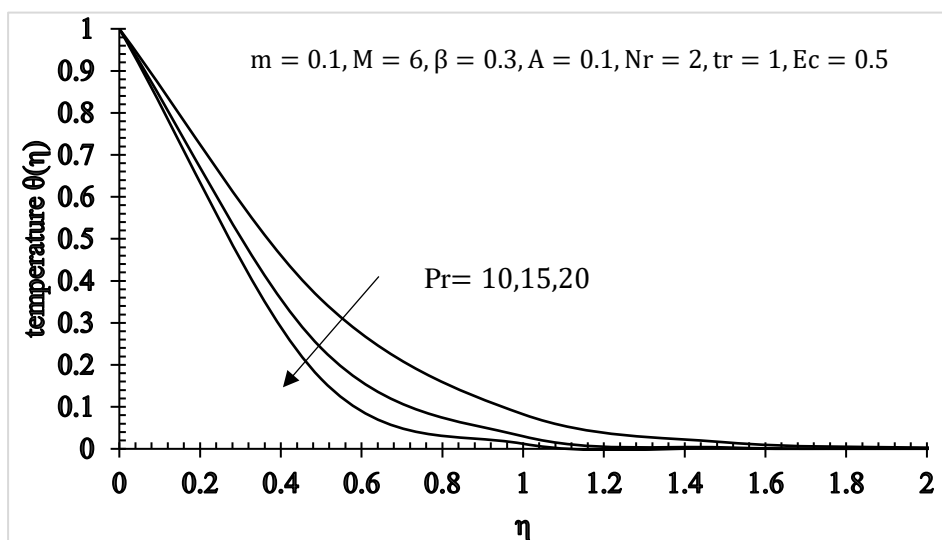
Figure 4.9: Change in $\theta(\eta)$ for ascending values of Pr .
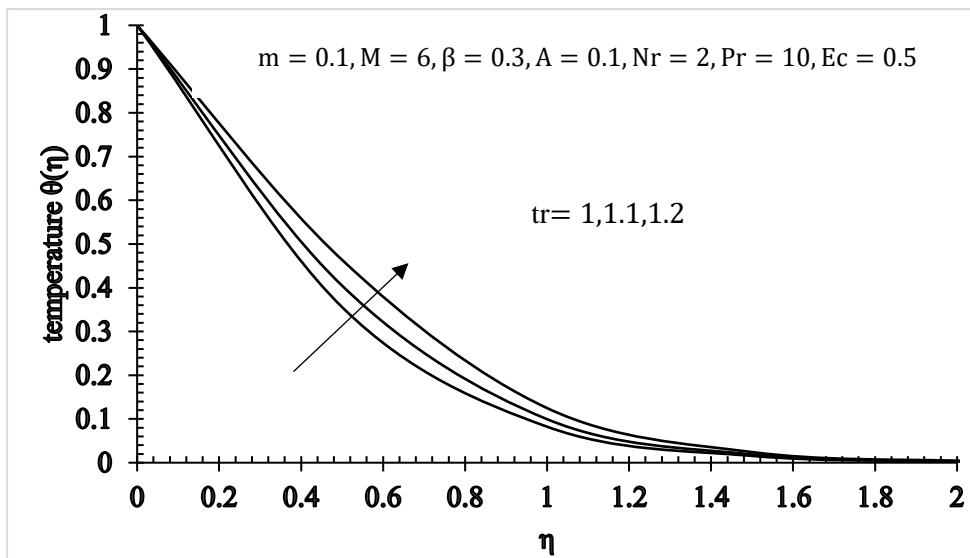
Figure 4.10: Change in $\theta(\eta)$ for ascending values of tr.
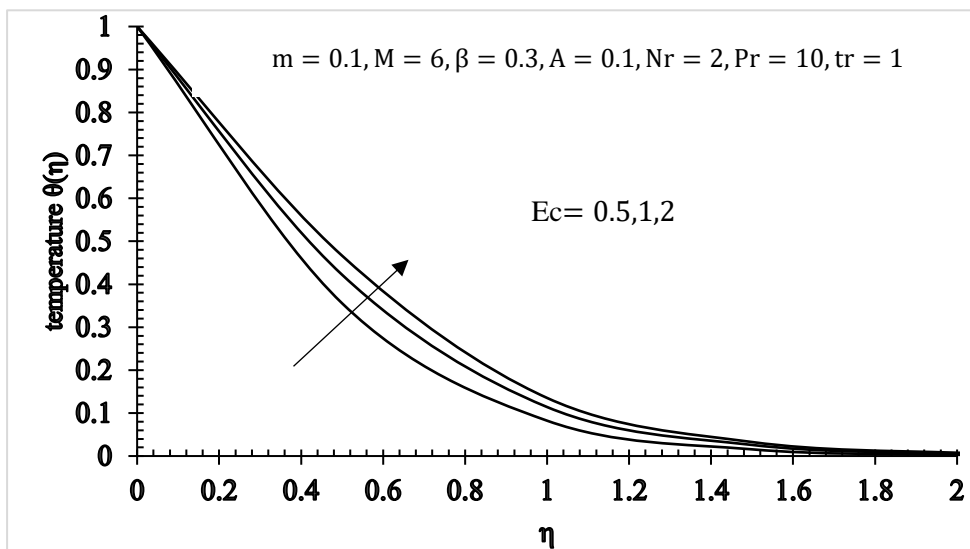
Figure 4.11: Change in $\theta(\eta)$ for ascending values of Ec.

5. Conclusion
Some interesting findings have been listed below.

- Due to the rising values of the magnetic parameter M, the velocity behavior decreases along $x-$ axis in Casson fluid.
- Due to the ascending values of the magnetic parameter M, the temperature behavior also increases in Casson fluid.
- Due to the accelerating values of Hall current m, the velocity rise in $z-$ axis and marginal increment found in x direction. While the marginal decrement found in the temperature profile in Casson fluid.
- Decrement is observed in the velocity behavior due to the rising values of the unsteadiness A. However, no significant change is prominent in the velocity profile along x direction in Casson fluid.

▪ An increment is observed in the temperature behavior due to the rising values of the unsteadiness A in Casson fluid.

▪ The fluid flow model presented in the paper has applications in silicon suspensions, blood flow, polymer engineering, and the printing industry.

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EXPLORING THE IMPACT OF THERMAL RADIATION, VISCOUS DISSIPATION, AND MAGNETIC FIELD ON MICROPOLAR FLUID FLOW OVER A SHRINKING SURFACE WITH VELOCITY SLIP

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Abstract

This study investigates the stagnation point flow of a micropolar fluid over a stretching/shrinking sheet with second-order velocity slip. This study also considered the effects of thermal radiation, viscous dissipation, and MHD. The partial differential equations governing the flow were transformed into ordinary differential equations by using the similarity transformation method. The numerical solution was obtained using the shooting technique with the fourth-order Adams-Moulton method. The effects of various parameters such as the micropolar parameter, magnetic field, Prandtl number, aligned angle of the magnetic field, stretching/shrinking rate, first- and second-order slip, suction parameter, viscous dissipation, and thermal radiation on the velocity, microrotation, and temperature profiles were analyzed using tables and graphs. The results obtained using the shooting technique with the fourth-order Adams-Moulton method were compared with the previous results and found to be in excellent agreement.

1. Introduction

The study of fluid on a stretching sheet is an important problem which has been discussed in the current era because of its importance in different processes of engineering like manufacturing processes such as glass fiber drawing, paper production and plastic extrusion by Thomason et al. [1]. Fluid mechanics deals with the behavior of fluids at rest and during motion. Zheng et al. [2] investigated the temperature effect with velocity slip on magnetohydrodynamics flow and heat transfer past a shrinking sheet.

Many researchers have studied micropolar fluids with different geometries. Eringen [3] was the first to investigate micropolar fluids. Ariman et al. [4] theoretically examined micropolar fluids and their applications. Ishak et al. [5] discussed the stagnation point flow of a micropolar fluid in 2D boundary layer flow of mixed convection on a stretching surface. Bhargava et al. [6] investigated solutions for micropolar transport owing to the nonlinear stretching sheet. Rees and Pop [7] theoretically discussed free convection from a vertical plate in a micropolar fluid. Nazar et al. [8], Ishak et al. [9], Hayat et al. [10], and Yacob et al. [11] also discussed the stagnation point flow of a micropolar fluid owing to a stretching sheet under different physical conditions.

The effect of the slip condition provides interesting results for different fluids. Dorrepaal [12] was the first one who introduced the slip velocity effect. Bellani and Variano [13] discussed the slip velocity effect on the turbulent flow. Wang [14] studied the slip effect on viscous flow due to a stretching sheet. Noghrehabadi et al. [15] investigated the partial slip effect on the heat transfer of nanofluids past a stretching sheet.

Magnetohydrodynamics (MHD) is a field of study that focuses on the magnetic properties of electrically conducting fluids. Many researchers have been interested in the study of MHD fluid flow because of its important applications in engineering processes. Alfven [16] was the first to introduce the effect of MHD on fluid flow. Yih [17] conducted a numerical study on the heat and mass transfer characteristics of magnetohydrodynamic free convection on a permeable vertical surface under continuous motion. Zheng et al. [18] investigated the flow and heat transfer in MHD over a shrinking porous sheet with temperature jump and velocity slip.

Radiation is a process by which heat is transferred through electromagnetic waves. It is the only heat transfer process that does not require a medium (i.e., molecules) to transfer energy from hot to cold regions. Makinde and Ogulu [19] explored the impact of thermal radiation on the heat and mass transfer of a fluid with a variable viscosity.

Sheikholeslami et al. [20] studied the impact of thermal radiation on MHD nanofluid flow between two rotating horizontal plates. Raptis et al. [21] and Arpaci [22] discussed the effect of thermal radiation under different physical conditions. The stagnation point of the MHD flow has been studied by numerous researchers in relation to various important effects [23-26].

A review by Sharma et al. [27] was presented, and the flow analysis was extended by considering thermal radiation and an aligned magnetic field. A similarity transformation is used to transform the modelled PDEs into a system of ODEs. The numerical results were obtained using the shooting technique and compared with those obtained using the built-in MATLAB solver bvp4c. The numerical results were analyzed for the behavior of different parameters using tables and graphs.

2. Mathematical Modeling

Consider a steady, 2D stagnation point flow of an incompressible micropolar fluid on a stretching/shrinking surface with the assumption of slip velocity effect. The free stream velocity has been represented by $u_e(x) = ax$ and the stretching/shrinking velocity by $u_w(x) = bx$. For the stretching sheet, b is taken positive whereas for the shrinking case, $b < 0$.
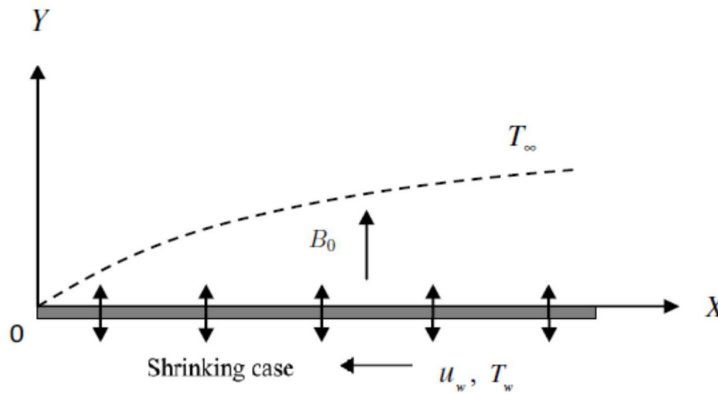
Figure 1. Geometry.

The mathematical model of the flow has been expressed as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$\frac{\partial u}{\partial x}u + \frac{\partial u}{\partial y}v = u_e\frac{\partial u_e}{\partial x} + \left(\frac{\mu + k}{\rho}\right)\frac{\partial^2 u}{\partial y^2} + \frac{k}{\rho}\frac{\partial N}{\partial y} - \frac{\sigma B_0^2}{\rho}\mathrm{Sin}^2(\alpha)(u - u_e), \tag{2}$$

$$\rho j\left(\frac{\partial N}{\partial x}u + \frac{\partial N}{\partial y}v\right) = \left(\mu + \frac{k}{2}\right)j\frac{\partial^2 N}{\partial y^2} - k\left(2N + \frac{\partial u}{\partial y}\right), \tag{3}$$

$$\frac{\partial T}{\partial x}u + \frac{\partial T}{\partial y}v = \alpha_1\left(\frac{\partial^2 T}{\partial y^2}\right) - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2, \tag{4}$$

where dynamic viscosity is denoted by μ, micro-rotation viscosity by k, fluid density by ρ, micro-inertia density by j, component of micro-rotation vector by N, fluid temperature by T, thermal diffusivity by α_1 and the radiative heat flux by q_r. The BCs for the above equations are:

$$v = -V_s,\ u_w(x) + u_{slip} = u,\ N = -n\frac{\partial u}{\partial y},\ T = T_w \text{ at } y = 0, \tag{5}$$

$$T = T_\infty,\ u \to u_e(x),\ N \to 0 \text{ as } y \to \infty. \tag{6}$$

In the above equations, suction/injection is denoted by V_s, where V_s is greater than zero for suction velocity and less than zero for injection velocity. The slip velocity has been represented by u_{slip}, the reference temperature by T_0 and ambient temperature by T_∞. Now, we use the following similarity variables:

$$\psi = \sqrt{vxu_e(x)}\,f(\eta) = \sqrt{avx}\,f(\eta),\ \eta = \sqrt{\frac{u_e(x)}{vx}}y = \sqrt{\frac{a}{v}}y, \tag{7}$$

$$N = u_e(x)\sqrt{\frac{u_e(x)}{vx}}h(\eta) = a\sqrt{\frac{a}{v}}xh(\eta), \tag{8}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty} \Rightarrow T = \theta(\eta)(T_w - T_\infty) + T_\infty, \tag{9}$$

where the kinematic viscosity has been represented by ν and the stream function by ψ.

The mathematical model of the present problem can be represented in dimensionless form as follows:

$$(1 + K)f''' + ff'' + (1 - f'^2) + Kh' - (f' - 1)M\sin^2(\alpha) = 0, \qquad (10)$$

$$\left(\frac{2 + K}{2}\right)h'' + fh' - f'h - K(2h + f'') = 0, \qquad (11)$$

$$\left(1 + \frac{4R}{3}\right)\theta'' + Prf\theta' + PrEcf'' = 0, \qquad (12)$$

along with BCs:

$$f(0) = \lambda_1, \quad f'(0) = \varepsilon + \lambda f''(0) + \delta f'''(0), \quad h(0) = -nf''(0), \quad \theta(0) = 1, \quad (13)$$

$$\theta(\eta) \to 0, \quad f'(\eta) \to 1, \quad h(\eta) \to 0, \text{ as } \eta \to \infty, \qquad (14)$$

where magnetic field has been represented by M, the micropolar parameter by K, the Prandtl number by $Pr = \frac{\nu}{\alpha}$, the suction/injection by λ_1, the stretching/shrinking rate by ε, the aligned angle of magnetic field by α, the first order slip denotes by λ and the second order slip by δ.

The skin friction coefficient and the Nusselt number are expressed as

$$C_f = \frac{\tau_w + kN}{\rho u_e^2}, \quad N_u = \frac{xq_w}{k(T - T_\infty)}, \qquad (15)$$

where the heat flux q_w and shear stress τ_w are expressed as

$$q_w = -k\left[1 + \frac{16\sigma^* T_3^\infty}{3k_1 k^*}\frac{\partial T}{\partial y}\right]_{y=0}, \quad \tau_w = \left[(\mu + k)\frac{\partial u}{\partial y}\right]_{y=0}. \qquad (16)$$

The dynamic viscosity has been represented by μ and the thermal diffusivity by k. By using (15) in (16), we get

$$C_f Re_x^{1/2} = [1 + (1 - n)K]f''(0), \quad Nu_x Re_x^{1/2} = -\left(1 + \frac{4R}{3}\right)\theta'(0). \qquad (17)$$

3. Solution Methodology

The system of equations (7)-(9) with the associated boundary conditions given by equation (10) is coupled and non-linear, so an approximate solution cannot be found directly. For this, we use the numerical technique, i.e., the shooting method, along with the Adams-Moulton method, to find the approximate solution. By making use of these techniques, we convert a system of higher- order ODEs into a set of first order ODEs:

$$f''' = \left(\frac{1}{1+K}\right)[M\sin^2(\alpha)(f'-1) - ff'' - Kh' - (1 - f'^2)], \qquad (18)$$

$$h'' = \left(\frac{2}{2+K}\right)[-fh' + f'h + K(2h + f'')], \qquad (19)$$

$$\theta'' = \left(\frac{3Pr}{3+4R}\right)(-f\theta' + Ecf''). \qquad (20)$$

For further proceeding, use the following notations:

$$f = y_1, \quad h = y_4, \quad \theta = y_6. \qquad (21)$$

The coupled nonlinear flow equations are turned into the subsequent system of seven first order ODEs, together with the initial conditions:

$$
\left.
\begin{aligned}
&y_1' = y_2, && y_1(0) = \lambda_1, \\
&y_2' = y_3, && y_2(0) = p, \\
&y_3^1 = -\frac{1}{(1+K)}[M\sin^2(\alpha)(y_2 - 1) - y_1 y_3 - (1 - y_2^2) - Ky_5], \\
&y_3(0) = \left(\frac{1+K}{(1+K)\lambda - \delta\lambda_1}\right) \\
&\qquad \times \left[p - \varepsilon - \delta\left(\frac{1}{1+K}\right)([M\sin^2(\alpha)(p-1) - (1 - p^2) - Kt])\right], \\
&y_4' = y_5, \\
&y_4(0) = \left(\frac{-n(1+K)}{(1+K)\lambda - \delta\lambda_1}\right) \\
&\qquad \times \left[p - \varepsilon - \delta\left(\frac{1}{1+K}\right)([M\sin^2(\alpha)(p-1) - (1 - p^2) - Kt])\right], \\
&y_5^1 = \frac{2}{(2+K)}[-y_1 y_5 + y_2 y_4 + K(2y_4 + y_3)], && y_5(0) = t, \\
&y_6' = y_7, && y_6(0) = 1, \\
&y_7' = -y_1 y_7 - Ecy_3^2\left(\frac{3Pr}{3+4R}\right), && y_7(0) = u
\end{aligned}
\right\}.
$$

To solve the above initial value problem with the Adams-Moulton method, we have to take some initial guesses for p, t and u. Newton's method is utilized to improve these original estimates of p, t and u until the following benchmark is achieved:

$$\max\{y_2(\eta_\infty,\ p,\ t,\ u) - 1, \quad y_4(\eta_\infty,\ p,\ t,\ u),\ y_6(\eta_\infty,\ p,\ t,\ u)\} < \varepsilon. \quad (22)$$

All the numerical results are attained with $\varepsilon = 10^{-6}$.

4. Results and Discussion

The main objective of the present section is to analyze the impact of various physical constraints such as micropolar K, magnetic field M, Prandtl number Pr, aligned angle of the magnetic field α, stretching/shrinking rate ε, first order slip λ, suction/injection λ_1, second order slip δ and the thermal radiation R on the velocity, microrotation, and energy profiles. The numerical results have been shown in the form of tables and graphs.

The results for the skin friction coefficient and Nusselt number are presented in Tables 1 and 2, respectively. We compare the obtained results by shooting technique with [27] and found both to be in excellent agreement. These tables indicate that by increasing K (micropolar parameter), C_{fx} is increased but Nu_x is reduced. By increasing M (magnetic field), C_{fx} is reduced and Nu_x is enhanced. By increasing Prandtl number Pr, there is no effect on C_{fx}, but Nu_x is increased. With decrease in aligned angle of magnetic field, local Nusselt number and C_{fx} get decreased. However, with increase in microrotation parameter n and the stretching rate ε, C_{fx} is reduced but Nu_x is enhanced. By increasing second-order slip parameter δ, C_{fx} is increased but Nu_x is reduced. By increasing first order slip parameter λ and suction parameter λ_1, C_{fx} is decreased and Nu_x is increased. With an increase in thermal radiation R, there is no effect on C_{fx}, but Nu_x is reduced.

Table 1. Numerical results of $C_f(Re_x)^{1/2}$ for different values of K, M, Pr, α, n, δ, ε, λ, λ_1 and R

K	M	Pr	α	n	δ	ε	λ	λ_1	R	Sharma et al. [27]	Present value
0.5	0.2	0.5	$\pi/2$	0.5	-0.5	-1.2	0.5	0.2	0.5	1.57495	1.57492900
1.2										1.94515	1.94587200
2.0										2.30618	2.2805290
3.0										2.68620	2.5371750
	0.8									1.56440	1.56427500
	2.0									1.51292	1.51264800
	4.0									1.42257	1.42220800
		0.6								1.57495	1.57500000
		0.7								1.57495	1.57500000
		0.8								1.57495	1.57500000
			$\pi/6$							1.57180	1.57181400
			$\pi/12$							1.57033	1.57035200
			$\pi/18$							1.56999	1.56989400
				0.6						1.51557	1.51480900
				0.7						1.45539	1.45393900
				0.8						1.39451	1.39240300
					-1.0					1.21699	1.16095600
					-0.05					1.92862	1.92887300
						-1.9				2.04407	2.04623600
						-1.7				1.92162	1.92281200
						-1.5				1.78638	1.78716300
							0.2			1.89113	1.89240600
							0.3			1.77533	1.77618000
							0.8			1.34347	1.34861100
								0.4		1.57660	1.57817000
								0.6		1.56769	1.56864700
								0.8		1.55107	1.55164800
									0.7	1.57495	1.57500000
									0.9	1.57495	1.57500000
									1.1	1.57495	1.57500000

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Table 2. Numerical results of $Nu_x(Re_x)^{1/2}$ for different values of K, M, Pr, α, n, δ, ε, λ, λ_1 and R

K	M	Pr	α	n	δ	ε	λ	λ₁	R	Sharma et al. [27]	Present value
0.5	0.2	0.5	π/2	0.5	-0.5	-1.2	0.5	0.2	0.5	0.64744	0.64516874
1.2										0.60581	0.60171650
2.0										0.56311	0.54425310
3.0										0.51637	0.52002320
	0.8									0.68099	0.68914070
	2.0									0.71478	0.71572640
	4.0									0.74091	0.74081010
		0.6								0.70554	0.69333740
		0.7								0.75906	0.75309280
		0.8								0.80897	0.80495540
			π/6							0.63458	0.63444040
			π/12							0.63097	0.63092660
			π/18							0.63022	0.62993030
				0.6						0.65403	0.65004970
				0.7						0.66051	0.65659830
				0.8						0.66687	0.66301820
					-1.0					0.69221	0.69522670
					-0.05					0.58035	0.58191850
						-1.9				0.54112	0.55384770
						-1.7				0.58219	0.58897820
						-1.5				0.61224	0.61527440
							0.2			0.58981	0.59555660
							0.3			0.61435	0.61712540
							0.8			0.67781	0.66548490
								0.4		0.73216	0.73779160
								0.6		0.81655	0.81280670
								0.8		0.90088	0.88922840
									0.7	0.70065	0.69991760
									0.9	0.75090	0.75893520
									1.1	0.79886	0.81777860

Figure 2 shows the impact of K (micropolar) on $f^1(\eta)$. This figure indicates that by increasing the micropolar parameter, the velocity profile is

reduced. Reverse flow is observed near the surface as the micropolar parameter (K) is increased.
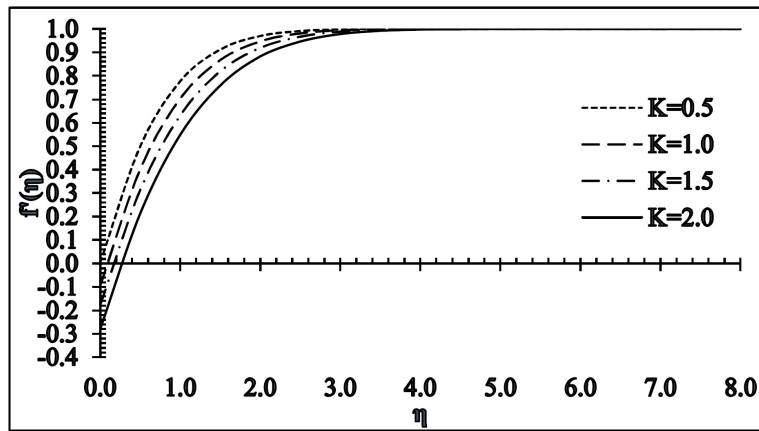
Figure 2. Consequences of K on $f'(\eta)$.
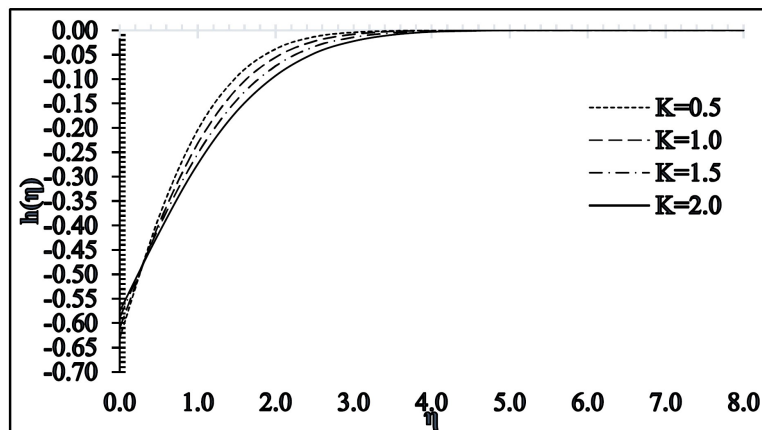
Figure 3. Consequences of K on h.

Figure 3 shows the impact of the micropolar parameters on the micro-rotation profile. By increasing the micropolar parameter K, the microrotation profile decreased in the lower half of the surface, whereas it increased in the upper half. The effect of K on $\theta(\eta)$ (temperature profile) is presented in Figure 4. By increasing K, the temperature profile is enhanced.
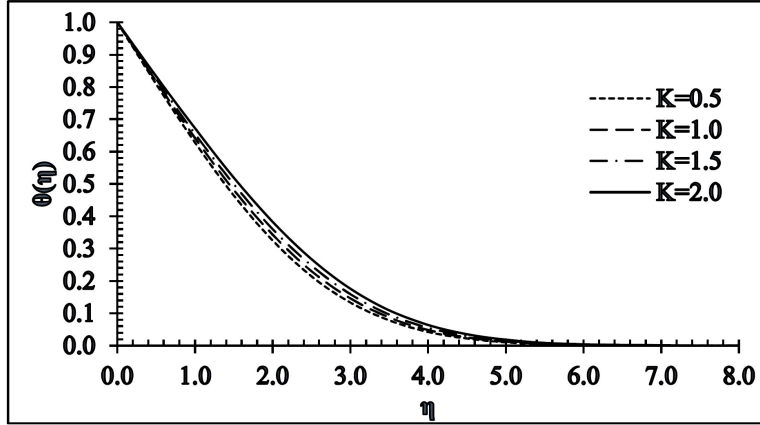
Figure 4. Consequences of K on $\theta(\eta)$.
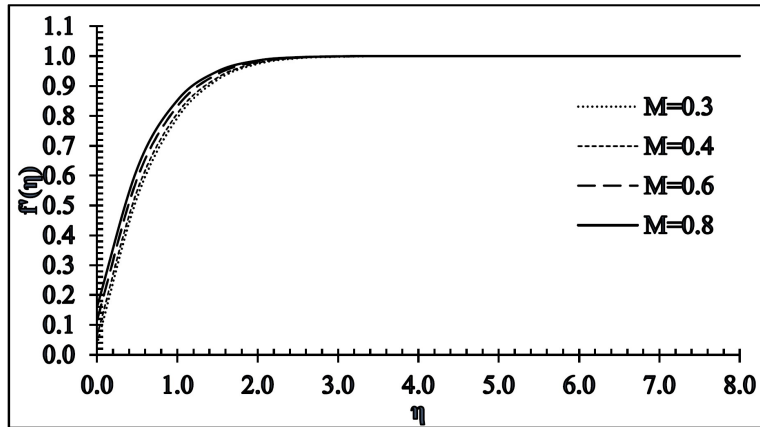
Figure 5. Consequences of K on $f'(\eta)$.

Figure 5 illustrates the changes in the velocity profile at various magnetic field strengths. As the magnetic field strength increased, the velocity profile increased. This phenomenon is a result of the magnetic field that enhances fluid motion within the boundary layer.

Figure 6 shows the variation in the micro-rotation profile for different estimations of the magnetic field M. By increasing M, the micro-rotation increased. Thus, the boundary layer thickness is decreased. Figure 7 shows

the impact of the magnetic parameter M on the temperature profile. By increasing M, the temperature profile is reduced.
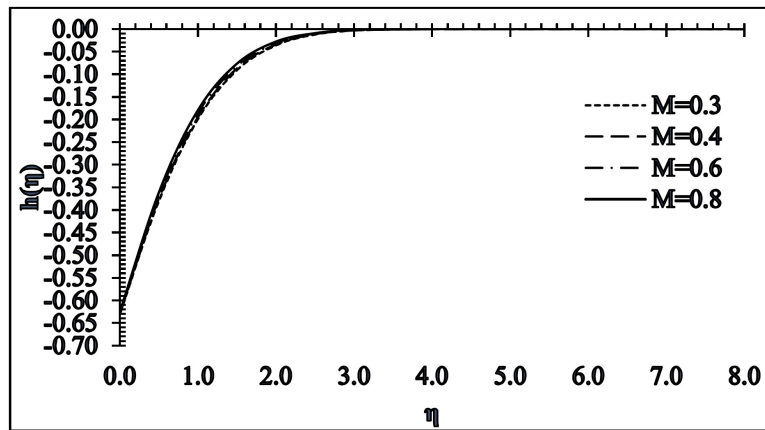
Figure 6. Consequences of K on h.
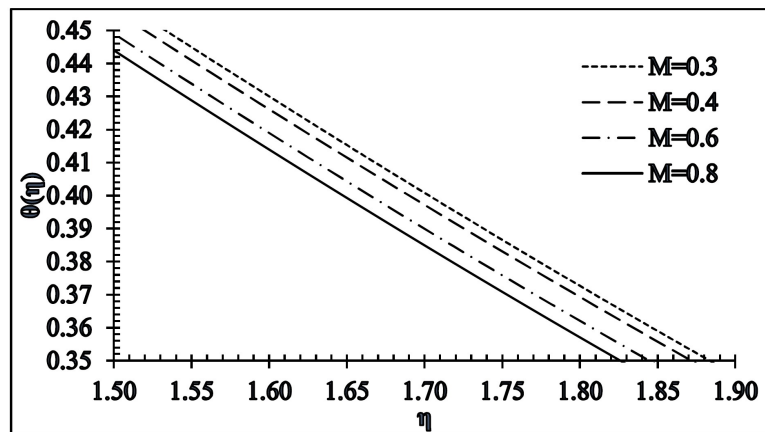
Figure 7. Consequences of K on $\theta(\eta)$.

Figures 8 and 9 demonstrate the variations in the velocity and micro-rotation profiles for different estimations of the shrinking parameter ε. It is noted that by increasing the shrinking parameter ε, the velocity profile and micro-rotation profile are increased. Figure 10 depicts the influence

of shrinking parameter ε on the energy profile. By increasing ε, the temperature profile is reduced.
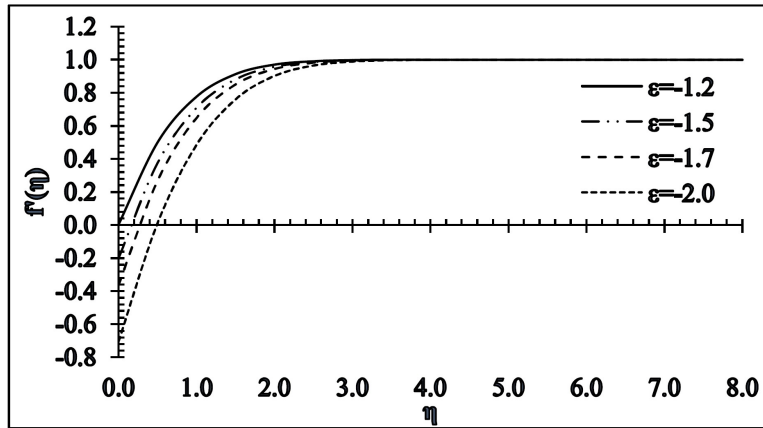
Figure 8. Consequences of ε on $f'(\eta)$.
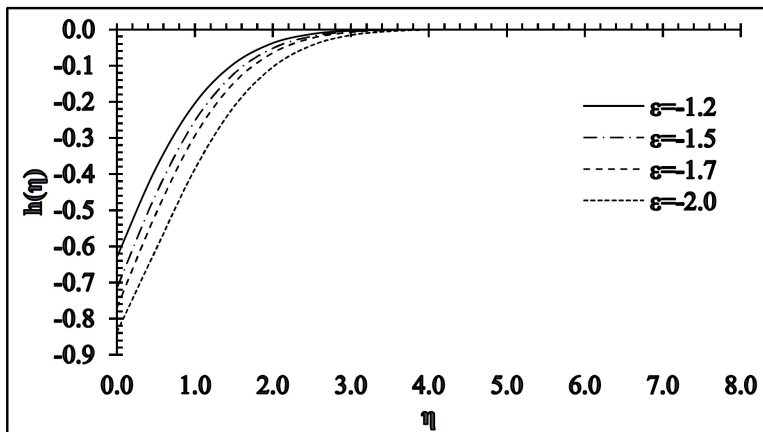
Figure 9. Consequences of ε on h.
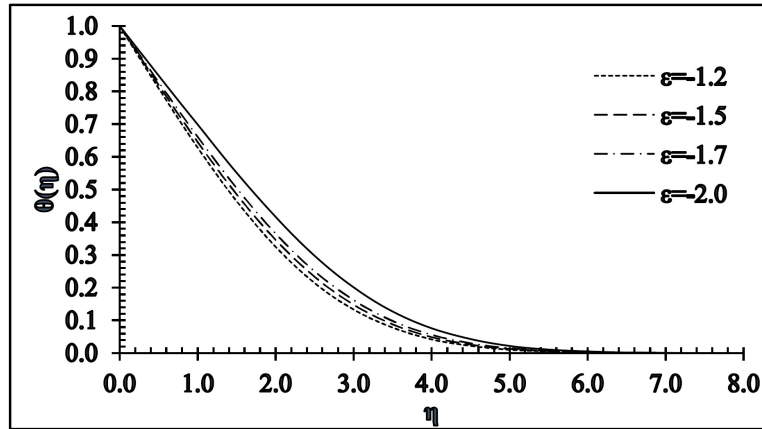
Figure 10. Consequences of ε on $\theta(\eta)$.

The effect of suction parameter λ_1 on the velocity profile is presented in Figure 11. It can be seen that by increasing λ_1, the velocity profile is increasing significantly. The variations in the micro-rotation profile for λ_1 are demonstrated in Figure 12. From this graph, increasing λ_1, the micro-rotation profile is enhanced. The thickness of boundary layer is reduced. Figure 13 displays the impact of the suction parameter λ_1 on the temperature profile. By increasing λ_1, the temperature profile is diminished.
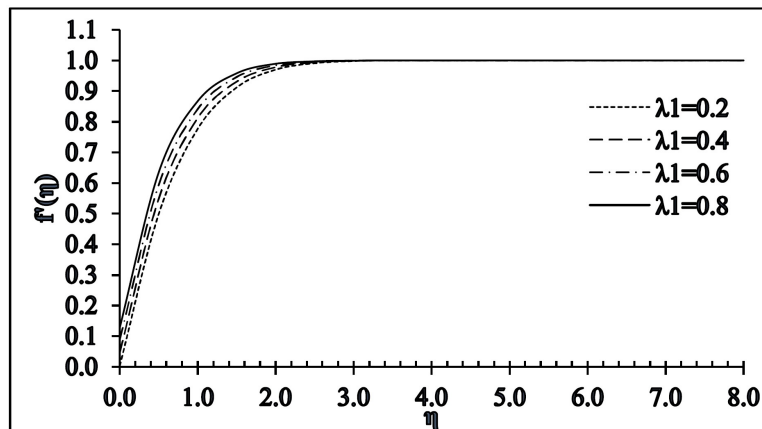
Figure 11. Consequences of λ_1 on $f'(\eta)$.
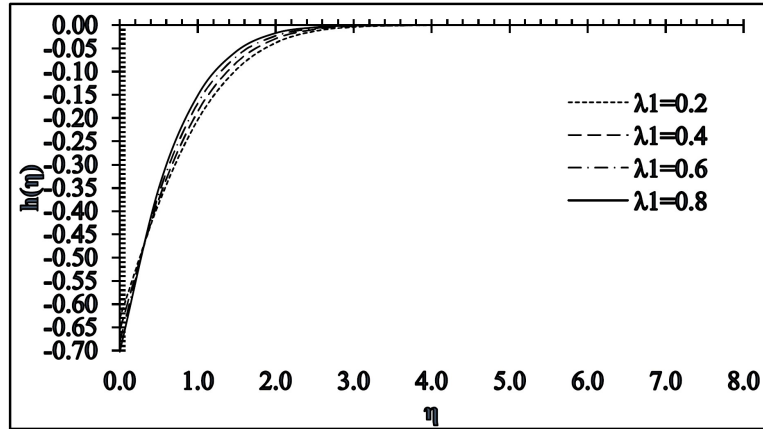
Figure 12. Consequences of λ_1 on h.
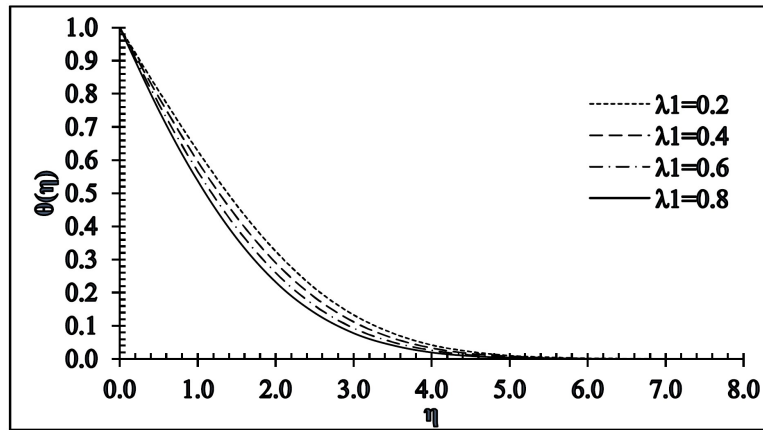
Figure 13. Consequences of λ_1 on $\theta(\eta)$.

The effect of Prandtl number *Pr* on the temperature profile is shown in Figure 14. It is observed that the greater *Pr* has weaker thermal diffusivity resulting in a low range temperature. The impact of *R* on temperature profile is seen in Figure 15. From this graph, by increasing *R*, the temperature profile is enhanced. Thus, the boundary layer thickness is increased.

Figure 16 plots the temperature distribution against the Eckert number. The graph shows a rising trend in the temperature field for dominant values

of *Ec*. This trend can be attributed to the strong frictional force between the fluid particles, which generates more heat in the flow for higher Eckert numbers, ultimately leading to an increase in temperature.
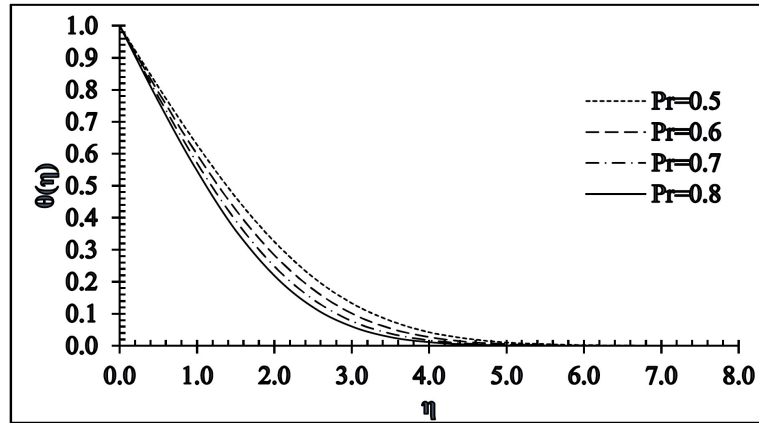
Figure 14. Consequences of *Pr* on $\theta(\eta)$.
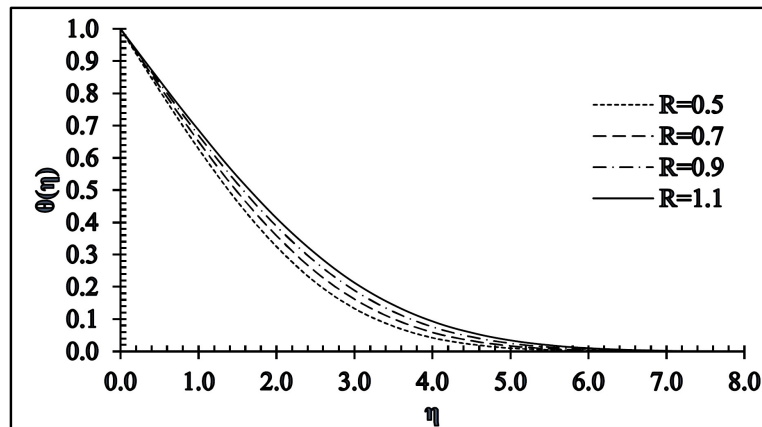
Figure 15. Consequences of *R* on $\theta(\eta)$.
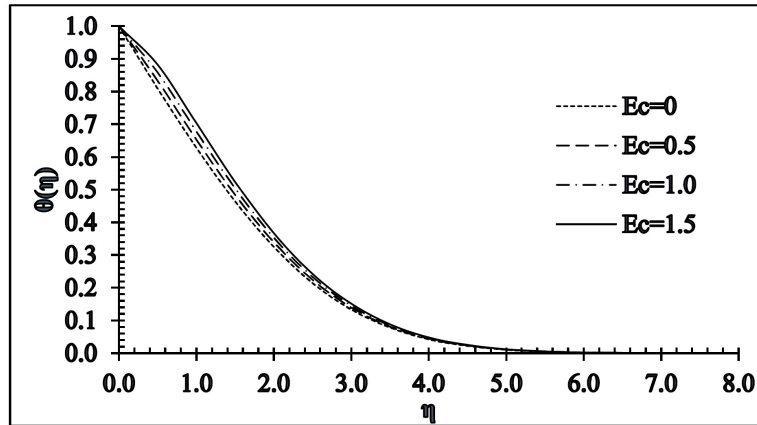
Figure 16. Consequences of *Ec* on θ(η).

5. Conclusion

- Increasing the shrinking parameter leads to a rise in the temperature profile and a decline in the velocity and micro-rotation profiles.

- Increasing the suction parameter, the velocity and microrotation profiles are increased and temperature profile is reduced.

- When the Prandtl number is raised, the temperature profile decreases, and the boundary layer thickness reduces.

- Temperature profile increases with increase in thermal radiation.

Acknowledgement

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On optimality and duality for multiobjective interval-valued programming problems with vanishing constraints

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Abstract

In this study, we explore the theoretical features of a multiobjective interval-valued programming problem with vanishing constraints. In view of this, we have defined a multiobjective interval-valued programming problem with vanishing constraints in which the objective functions are considered to be interval-valued functions, and we define an LU-efficient solution by employing partial ordering relations. Under the assumption of generalized convexity, we investigate the optimality conditions for a (weakly) LU-efficient solution to a multiobjective interval-valued programming problem with vanishing constraints. Furthermore, we establish Wolfe and Mond–Weir duality results under appropriate convexity hypotheses. The study concludes with examples designed to validate our findings.

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Keywords: Multiobjective interval-valued optimization problem; vanishing constraints; (weakly) LU-efficient solution; duality.

1 Introduction

In modern mathematical research, the concept of mathematical programming with vanishing constraints has emerged as a novel type of constrained optimization problems. Formal analysis was conducted by Achtziger and Kanzow [1]. Dorsch, Shikhman, and Stein [9] presented a topological analysis of mathematical programs with vanishing constraints and introduced the new concept of a T-stationary point. By applying the concept of local regularization to mathematical programs with vanishing constraints, Hohesiel, Kanzow, and Schwartz [13] derived a new solution method for solving such a class of optimization problems and proved several convergence results. Later, to compute the mathematical problems involving vanishing constraints numerically, Hoheisel et al. [14] investigated and compared four regularization methods, each impacted by a single regularization parameter. The study of mathematical programming with vanishing constraints has a wide range of real-world applications, including the development of robot motion plans [8, 19], the design of optimal truss topologies for mechanical structures [11], and the design of nonlinear optimal control problems for mixed integers [20]. A multiobjective programming problem involves minimizing multiple objectives over a set of feasible solutions. Multiobjective programming is challenging due to the fact that the objectives for vector optimization problems compete with each other, and an improvement on one objective can reduce goals for other objectives. There is an enormous amount of literature on optimal conditions and numerous kinds of dualities in multiobjective programming problems (see, for example, [7, 22, 23]). A constraint qualification is an element critical to the existence of Lagrange multipliers in multiobjective optimization problems, as it allows Karush–Kuhn–Tucker optimality conditions to hold, thereby assisting with and enhancing optimization algorithms design. There have been several recent articles published on optimality, stationarity, criticality, and constraint qualification; for instance, we refer to [10, 12, 17]. Jayswal and Singh [18] studied about modified objective function approach for an equivalent η-approximated multiobjective optimization problem with vanishing constraints and also discussed saddle point criteria. The class of differentiable semi-infinite multiobjective programming problems with vanishing constraints was discussed by Antczak [4].

Using separate considerations of minimization and maximization, Ishibuchi and Tanaka [16] investigated multiobjective optimization problems in which the objective functions are interval-valued and developed an ordering relationship between two closed intervals. A general methodology proposed by Urli and Nadeau [26] provides a way of formulating the non-deterministic multiobjective linear programming problem with interval coefficients in a de-

terministic way and then solving it with an interactive approach. Under certain convexity assumptions, The Karush–Kuhn–Tucker necessary optimality conditions for nonlinear differentiable multiobjective programming problems with an interval-valued objective and constraint functions were derived by Hosseinzade and Hassanpour [15]. Studies on optimality conditions and different types of duality for multiobjective programming problems with interval objective function are quite widespread (refer to [6, 27, 28, 15, 21]). In this paper, we aim to investigate the optimality conditions and the duality results for multiobjective interval-valued programming problems with vanishing constraints under the Abadie constraint qualification.

Following is an outline of the rest of this paper: Section 2 consists of some basic definitions, background material, and the necessary optimality conditions. Section 3 represents the sufficient optimality conditions for multiobjective interval-valued optimization problems with vanishing constraints. In Sections 4 and 5, Wolfe type dual and Mond–Weir type dual are presented, and appropriate duality results are also discussed. Section 6 explores special cases. Finally, the paper is concluded in Section 7.

2 Preliminaries

This section contains a list of notations and basic definitions which will be used throughout the article. Let R^n be the Euclidean space with n-dimensions and R^n_+ be its nonnegative orthant. For a given a, $\Theta(a)$ is the system of the neighborhoods of a. For $A \subseteq R^n$, $span A$ and $pos A$ stands for its linear hull and convex cone (containing the origin) of A, respectively. Let $A \neq \phi$ and let the contingent cone of set A at the point a, be denoted by $\mathbb{T}(A, a)$. Let $I(R)$ be the set of all closed and bounded intervals in R. For the case where $\Lambda_1 \in I(R)$ is a closed interval, we use the notation $\Lambda_1 = [\alpha_0^L, \alpha_0^U]$, where α_0^L and α_0^U represent the minimum and maximum values of Λ_1, respectively. Let

$$\Lambda_1 = [\alpha_0^L, \alpha_0^U], \quad \Lambda_2 = [\beta_0^L, \beta_0^U] \in I(R).$$

Then we have

(i) $\Lambda_1 + \Lambda_2 = \{\alpha_0 + \beta_0 \mid \alpha_0 \in \Lambda_1 \text{ and } \beta_0 \in \Lambda_2\} = [\alpha_0^L + \beta_0^L, \alpha_0^U + \beta_0^U]$,

(ii) $-\Lambda_1 = \{\alpha_0 \mid \alpha_0 \in \Lambda_1\} = [-\alpha_0^U, -\alpha_0^L]$,

(iii) $\Lambda_1 - \Lambda_2 = \Lambda_1 + (-\Lambda_2) = [\alpha_0^L - \beta_0^U, \alpha_0^U - \beta_0^L]$,

(iv) $k\Lambda_1 = \{k\alpha_0 \mid \alpha_0 \in \Lambda_1\} = \begin{cases} [k\alpha_0^L, k\alpha_0^U], & \text{if } k \geq 0, \\ [k\alpha_0^U, k\alpha_0^L], & \text{if } k < 0, \end{cases}$ where k is a real number.

The real number $k \in R$ is equivalent to the closed interval $\Lambda_{1_k} = [k, k]$. Let $\Lambda_1 = [\alpha_0^L, \alpha_0^U] \in I(R)$ be a closed interval. We write the sum of an interval $\Lambda_1 \in I(R)$ and a real number k as $\Lambda_1 + \Lambda_{1_k}$. Thus, $\Lambda_1 + k = \Lambda_1 + \Lambda_{1_k} = [\alpha_0^L + k, \alpha_0^U + k]$.

For $\Lambda_1 = [\alpha_0^L, \alpha_0^U]$ and $\Lambda_2 = [\beta_0^L, \beta_0^U]$, the order relation $\preceq_{LU}$ is defined as follows:

(i) $\Lambda_1 \preceq_{LU} \Lambda_2$ if and only if $\alpha_0^L \leq \beta_0^L$ and $\alpha_0^U \leq \beta_0^U$.

(ii) $\Lambda_1 \prec_{LU} \Lambda_2$ if and only if $\Lambda_1 \preceq_{LU} \Lambda_2$ and $\Lambda_1 \neq \Lambda_2$.
It is obvious that, $\Lambda_1 \prec_{LU} \Lambda_2$ if and only if

$$\alpha_0^L < \beta_0^L \quad \text{and} \quad \alpha_0^U < \beta_0^U,$$

$$\text{or,} \qquad \alpha_0^L \leq \beta_0^L \quad \text{and} \quad \alpha_0^U < \beta_0^U,$$

$$\text{or,} \qquad \alpha_0^L < \beta_0^L \quad \text{and} \quad \alpha_0^U \leq \beta_0^U.$$

Furthermore, for $\dot{u}, \dot{v} \in R^m$, we use the following notations:

$(i).$ $\dot{u} \prec \dot{v} \Leftrightarrow \dot{u}_i < \dot{v}_i$, for all $i \in \{1, 2, \ldots, m\}$, $\dot{u} \not\prec \dot{v}$ is the negation of $\dot{u} \prec \dot{v}$

$(ii).$ $\dot{u} \preceq \dot{v} \Leftrightarrow \begin{cases} \dot{u}_i \leq \dot{v}_i, \text{ for all } i \in \{1, 2, \ldots, m\} \\ \dot{u}_{i_0} < \dot{v}_{i_0}, \text{ for at least one } i_0 \in \{1, 2, \ldots, m\}, \end{cases}$
$\dot{u} \not\preceq \dot{v}$ is the negation of $\dot{u} \preceq \dot{v}$.

In the present analysis, we consider the following differentiable vector optimization problem with multiple interval-valued objective function with vanishing constraints (MIVVC):

$$\begin{aligned}
\text{MIVVC} \qquad &\min \quad \vartheta(\xi) = (\vartheta_1(\xi), \vartheta_2(\xi), \ldots, \vartheta_m(\xi)) \\
&\text{subject to} \\
&\tau_i(\xi) \leq 0, \quad \text{for all } i = 1, 2, \ldots, p, \\
&\sigma_i(\xi) = 0, \quad \text{for all } i = 1, 2, \ldots, q, \\
&\rho_i(\xi) \geq 0, \quad \text{for all } i = 1, 2, \ldots, r, \\
&\omega_i(\xi)\rho_i(\xi) \leq 0, \quad \text{for all } i = 1, 2, \ldots, r,
\end{aligned}$$

where each $\vartheta_i : R^n \to I(R), i \in T = \{1, 2, \ldots, m\}$ is an interval-valued function; that is, $\vartheta_i(\xi) = [\vartheta_i^L(\xi), \vartheta_i^U(\xi)], i \in T$ and $\tau_i(i = 1, 2, \ldots, p)$, $\sigma_i(i = 1, 2, \ldots, q)$, $\rho_i, \omega_i(i = 1, 2, \ldots, r)$ are assumed to be continuously differentiable functions from $R^n \to R$. Let us denote $T_\tau := \{1, 2, \ldots, p\}$, $T_\sigma := \{1, 2, \ldots, q\}$, and $T_r := \{1, 2, \ldots, r\}$. The feasible solution set of MIVVC is given by

$$\mathbb{F}_{\mathbb{VC}} = \left\{ \xi \in R^n \mid \tau_i(\xi) \leq 0, \quad \text{for all } i = 1, 2, \ldots, p, \right.$$

$$\sigma_i(\xi) = 0, \quad \text{for all } i = 1, 2, \ldots, q,$$
$$\rho_i(\xi) \geq 0, \quad \text{for all } i = 1, 2, \ldots, r,$$
$$\omega_i(\xi)\rho_i(\xi) \leq 0, \quad \text{for all } i = 1, 2, \ldots, r \Big\}.$$

Definition 1. A point $a \in \mathbb{F}_{\mathbb{VC}}$ is said to be a locally LU-efficient solution of MIVVC, if there exists a neighborhood $U \in \Theta(a)$ such that there is no $\xi \in \mathbb{F}_{\mathbb{VC}} \cap \mathbb{U}$ satisfying

$$\vartheta(\xi) \preceq_{LU} \vartheta(a).$$

Definition 2. A point $a \in \mathbb{F}_{\mathbb{VC}}$ is said to be a locally weakly LU-efficient solution of MIVVC, if there exists a neighborhood $U \in \Theta(a)$ such that there is no $\xi \in \mathbb{F}_{\mathbb{VC}} \cap \mathbb{U}$ satisfying

$$\vartheta(\xi) \prec_{LU} \vartheta(a).$$

Let $a \in \mathbb{F}_{\mathbb{VC}}$ be any feasible solution of the MIVVC. The following index sets will be used:

$$T_+(a) := \{i \in T_r \mid \rho_i(a) > 0\},$$
$$T_0(a) := \{i \in T_r \mid \rho_i(a) = 0\}.$$

Furthermore, the index set T_+ can be divided into the following subsets

$$T_{+0}(a) := \{i \in T_r \mid \rho_i(a) > 0, \ \omega_i(a) = 0\},$$

$$T_{+-}(a) := \{i \in T_r \mid \rho_i(a) > 0, \ \omega_i(a) < 0\}.$$

Similarly, the index set T_0 can be partitioned in the following way

$$T_{0+}(a) := \{i \in T_r \mid \rho_i(a) = 0, \ \omega_i(a) > 0\},$$

$$T_{00}(a) := \{i \in T_r \mid \rho_i(a) = 0, \ \omega_i(a) = 0\},$$

$$T_{0-}(a) := \{i \in T_r \mid \rho_i(a) = 0, \ \omega_i(a) < 0\}.$$

Definition 3. A point $a \in \mathbb{F}_{\mathbb{VC}}$ is said to be a strong stationary point of MIVVC if and only if there exists $(\alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i \in T} (\alpha_i^L + \alpha_i^U) = 1, \lambda_{T_+(a)}^\rho = 0, \lambda_{T_{00}(a) \cup T_{0-}(a)}^\rho \geq 0,$ $\lambda_{T_{+-}(a) \cup T_{0+}(a) \cup T_{00}(a) \cup T_{0-}(a)}^\omega = 0$ and $\lambda_{T_{+0}(a)}^\omega \geq 0$ such that

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(a) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(a) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(a) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(a)$$
$$+ \sum_{i \in T_{+0}} \lambda_i^\omega \nabla \omega_i(a) - \sum_{i \in T_{0+} \cup T_{00} \cup T_{0-}} \lambda_i^\rho \nabla \rho_i(a) = 0.$$

Definition 4. A point $a \in \mathbb{F}_{\mathbb{VC}}$ is said to be a VC-stationary point of MIVVC if and only if there exists $(\alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times$

$R^r \times R^r$ with $\sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1, \lambda_{T_+(a)}^\rho = 0, \lambda_{T_{00}(a) \cup T_{0-}(a)}^\rho \geq 0,$

$\lambda_{T_{+-}(a) \cup T_{0+}(a) \cup T_{00}(a) \cup T_{0-}(a)}^\omega = 0$ and $\lambda_{T_{+0}(a) \cup T_{00}(a)}^\omega \geq 0$ such that

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(a) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(a) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(a) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(a)$$

$$- \sum_{i \in T_{0+} \cup T_{00} \cup T_{0-}} \lambda_i^\rho \nabla \rho_i(a) + \sum_{i \in T_{+0}} \lambda_i^\omega \nabla \omega_i(a) = 0.$$

For $a \in \mathbb{F}_{\mathbb{VC}}$ and $(\lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^p \times R^q \times R^r \times R^r$, let us define

$$T_\tau^+(a) := \{i \in T_\tau(a) \mid \lambda_i^\tau > 0\},$$

$$T_\sigma^+(a) := \{i \in T_\sigma(a) \mid \lambda_i^\sigma > 0\}, \ T_\sigma^-(a) := \{i \in T_\sigma(a) \mid \lambda_i^\sigma < 0\},$$

$$\hat{T}_+^+(a) := \{i \in T_+(a) \mid \lambda_i^\rho > 0\},$$

$$\hat{T}_0^+(a) := \{i \in T_0(a) \mid \lambda_i^\rho > 0\}, \ \hat{T}_0^-(a) := \{i \in T_0(a) \mid \lambda_i^\rho < 0\},$$

$$\hat{T}_{0+}^+(a) := \{i \in T_{0+}(a) \mid \lambda_i^\rho > 0\}, \ \hat{T}_{0+}^-(a) := \{i \in T_{0+}(a) \mid \lambda_i^\rho < 0\},$$

$$\hat{T}_{00}^+(a) := \{i \in T_{00}(a) \mid \lambda_i^\rho > 0\}, \ \hat{T}_{00}^-(a) := \{i \in T_{00}(a) \mid \lambda_i^\rho < 0\},$$

$$\hat{T}_{0-}^+(a) := \{i \in T_{0-}(a) \mid \lambda_i^\rho > 0\},$$

$$T_{+0}^+(a) := \{i \in T_{+0}(a) \mid \lambda_i^\omega > 0\}, \ T_{+0}^-(a) := \{i \in T_{+0}(a) \mid \lambda_i^\omega < 0\},$$

$$T_{+-}^+(a) := \{i \in T_{+-}(a) \mid \lambda_i^\omega > 0\},$$

$$T_{0+}^+(a) := \{i \in T_{0+}(a) \mid \lambda_i^\omega > 0\}, \ T_{0+}^-(a) := \{i \in T_{0+}(a) \mid \lambda_i^\omega < 0\},$$

$$T_{00}^+(a) := \{i \in T_{00}(a) \mid \lambda_i^\omega > 0\}, \ T_{00}^-(a) := \{i \in T_{00}(a) \mid \lambda_i^\omega < 0\},$$

$$T_{0-}^+(a) := \{i \in T_{0-}(a) \mid \lambda_i^\omega > 0\}.$$

Definition 5. Let $a \in \mathbb{F}_{\mathbb{VC}}$.

(i) The linearized cone of MIVVC at a is
$L(a) := \{d \in \mathbb{R}^n \mid \langle \nabla \tau_i(a), \ d \rangle \leq 0 \ (i \in T_\tau), \langle \nabla \sigma_i(a), \ d \rangle = 0 \ (i \in T_\sigma),$
$\langle \nabla \rho_i(a), \ d \rangle = 0 \ (i \in T_{0+}), \langle \nabla \rho_i(a), \ d \rangle \geq 0 \ (i \in T_{00} \cup T_{0-}),$
$\langle \nabla \omega_i(a), \ d \rangle \leq 0 \ (i \in T_{+0})\}.$

(ii) The VC-linearized cone of MIVVC at a is
$L_{VC}(a) := \{d \in \mathbb{R}^n \mid \langle \nabla \tau_i(a), \ d \rangle \leq 0 \ (i \in T_\tau), \langle \nabla \sigma_i(a), \ d \rangle = 0 \ (i \in T_\sigma),$
$\langle \nabla \rho_i(a), \ d \rangle = 0 \ (i \in T_{0+}), \langle \nabla \rho_i(a), \ d \rangle \geq 0 \ (i \in T_{00} \cup T_{0-}),$
$\langle \nabla \omega_i(a), \ d \rangle \leq 0 \ (i \in T_{+0} \cup T_{00})\}.$

Definition 6. The Abadie constraint qualification (MIVVC-ACQ) is said to hold at $a \in \mathbb{F}_{\mathbb{VC}}$ if
$$L(a) \subseteq \mathbb{T}(\mathbb{F}_{\mathbb{VC}}, a).$$

Definition 7. The vanishing Abadie constraint qualification (MIVVC-VACQ) is said to hold at $a \in \mathbb{F}_{\mathbb{VC}}$ if

$$L_{VC}(a) \subseteq \mathbb{T}(\mathbb{F}_{\mathbb{VC}}, a).$$

The following theorem can be written in a similar way to Proposition 1 of Tung [25].

Theorem 1 (Necessary optimality conditions)**.** Let ξ_0 be a locally weakly LU-efficient solution of primal problem MIVVC and also further assume that if MIVVC-VACQ holds at ξ_0 and the set

$$\Delta_1 := pos\left(\bigcup_{i \in T_\tau} \nabla \tau_i(\xi_0) \ \cup \bigcup_{i \in T_{00} \cup T_{0-}} (-\nabla \rho_i(\xi_0)) \ \cup \bigcup_{i \in T_{+0} \cup T_{00}} \nabla \omega_i(\xi_0)\right)$$

$$+ span\left(\bigcup_{i \in T_\sigma} \nabla \sigma_i(\xi_0) \ \cup \bigcup_{i \in T_{0+}} \nabla \rho_i(\xi_0)\right)$$

is closed, then there exists $(\alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i \in T}(\alpha_i^L + \alpha_i^U) = 1, \lambda_{T_+(\xi_0)}^\rho = 0, \lambda_{T_{00}(\xi_0) \cup T_{0-}(\xi_0)}^\rho \geq 0, \lambda_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)}^\omega = 0$ and $\lambda_{T_{+0}(\xi_0) \cup T_{00}(\xi_0)}^\omega \geq 0$ such that

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(a) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(a) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(a) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(a)$$

$$- \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(a) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(a) = 0.$$

3 Sufficient optimality conditions

In this section, we establish sufficient optimality conditions for the problem MIVVC using the concept of generalized convexity.

Theorem 2. Let ξ_0 be a strong stationary point of MIVVC. Suppose that $\hat{T}_{0+}^- \cup T_{+0}^+ = \phi$ and $\tau_i \ (i \in T_\tau)$, $\sigma_i \ (i \in T_\sigma^+)$, $-\sigma_i \ (i \in T_\sigma^-)$, $\omega_i \ (i \in T_{+0}^+)$, $-\rho_i \ (i \in \hat{T}_{0+}^+ \cup \hat{T}_{00}^+ \cup \hat{T}_{0-}^+)$ are quasiconvex functions at ξ_0. If $\sum_{i \in T} \alpha_i^L \vartheta_i^L(\cdot) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\cdot)$ is pseudoconvex function at ξ_0, then ξ_0 is an LU-efficient solution of MIVVC.

Proof. Since ξ_0 is a strong stationary point of MIVVC, there exists $(\alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i \in T}(\alpha_i^L + \alpha_i^U) = 1, \lambda_{T_+}^\rho = 0, \lambda_{T_{00} \cup T_{0-}}^\rho \geq 0, \lambda_{T_{+-} \cup T_{0+} \cup T_{0-}}^\omega = 0$ and $\lambda_{T_{+0}}^\omega \geq 0$ such that

$$\sum_{i\in T}\alpha_i^L\nabla\vartheta_i^L(\xi_0)+\sum_{i\in T}\alpha_i^U\nabla\vartheta_i^U(\xi_0)+\sum_{i\in T_\tau}\lambda_i^\tau\nabla\tau_i(\xi_0)+\sum_{i\in T_\sigma}\lambda_i^\sigma\nabla\sigma_i(\xi_0)$$

$$-\sum_{i\in T_r}\lambda_i^\rho\nabla\rho_i(\xi_0)+\sum_{i\in T_r}\lambda_i^\omega\nabla\omega_i(\xi_0)=0. \tag{1}$$

For an arbitrary $\xi\in\mathbb{F}_{\mathbb{VC}}$, we get $\tau_i(\xi)\le 0=\tau_i(\xi_0)$ for each $i\in T_\tau$. Thus the quasiconvexity at ξ_0 of τ_i $(i\in T_\tau)$ gives that

$$\langle\nabla\tau_i(\xi_0),\xi-\xi_0\rangle\le 0,\quad\text{for all }i\in T_\tau,$$

consequently, together with $\lambda_i^\tau\in\mathbb{R}^p$ leads that

$$\left\langle\sum_{i\in T_\tau}\lambda_i^\tau\nabla\tau_i(\xi_0),\xi-\xi_0\right\rangle\le 0. \tag{2}$$

We deduce from $\xi,\xi_0\in\mathbb{F}_{\mathbb{VC}}$ that $\sigma_i(\xi)=\sigma_i(\xi_0)=0,\quad\text{for all }i\in T_\sigma$, and hence,

$$\sigma_i(\xi)\le\sigma_i(\xi_0)=0,\quad\text{for all }i\in T_\sigma^+\text{ and }-\sigma_i(\xi)\le-\sigma_i(\xi_0)=0,\quad\text{for all }i\in T_\sigma^-.$$

The above inequalities along with the quasiconvexity at ξ_0 of σ_i $(i\in T_\sigma^+)$ and $-\sigma_i$ $(i\in T_\sigma^-)$ ensure that

$$\langle\nabla\sigma_i(\xi_0),\xi-\xi_0\rangle\le 0,\quad\text{for all }i\in T_\sigma^+\text{ and }\langle-\nabla\sigma_i(\xi_0),\xi-\xi_0\rangle\le 0,\quad\text{for all }i\in T_\sigma^-.$$

Thus, taking into account the definitions of T_σ^+,T_σ^- results in

$$\left\langle\sum_{i\in T_\sigma}\lambda_i^\sigma\nabla\sigma_i(\xi_0),\xi-\xi_0\right\rangle\le 0. \tag{3}$$

Again, we deduce from $\xi\in\mathbb{F}_{\mathbb{VC}}$ that $-\rho_i(\xi)\le 0,\omega_i(\xi)\ge 0,\quad\text{for all }i\in T_r$. Thus,

$$\begin{cases} -\rho_i(\xi)\le-\rho_i(\xi_0), & i\in\hat{T}_{0+}^+\cup\hat{T}_{00}^+\cup\hat{T}_{0-}^+, \\ \omega_i(\xi)\le\omega_i(\xi_0), & i\in T_{+0}^+. \end{cases}$$

Therefore, the quasiconvexity of $-\rho_i,i\in\hat{T}_{0+}^+\cup\hat{T}_{00}^+\cup\hat{T}_{0-}^+$ and $\omega_i,i\in T_{+0}^+$ at ξ_0 yields that

$$\langle-\nabla\rho_i(\xi_0),\xi-\xi_0\rangle\le 0,\quad\text{for all }i\in\hat{T}_{0+}^+\cup\hat{T}_{00}^+\cup\hat{T}_{0-}^+, \tag{4}$$

$$\langle\nabla\omega_i(\xi_0),\xi-\xi_0\rangle\le 0,\quad\text{for all }i\in T_{+0}^+. \tag{5}$$

As $T_{+0}^+\cup\hat{T}_{0+}^-=\phi$, we presume from (1)–(5) that

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\xi_0), \xi - \xi_0 \right\rangle$$

$$= \left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\xi_0) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\xi_0) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\xi_0) + \right.$$

$$\left. \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\xi_0), \xi - \xi_0 \right\rangle \geq 0, \tag{6}$$

for all $\xi \in \mathbb{F}_{\mathbb{VC}}$.

On the contrary, suppose ξ_0 is not an LU-efficient solution of MIVVC. This leads to the existence of a feasible point $\tilde{\xi} \in \mathbb{F}_{\mathbb{VC}}$ such that

$$\vartheta(\tilde{\xi}) \preceq_{LU} \vartheta(\xi_0);$$

that is, for $i \in T$,

$$\left\{ \begin{array}{l} \vartheta_i^L(\tilde{\xi}) < \vartheta_i^L(\xi_0) \\ \vartheta_i^U(\tilde{\xi}) \leq \vartheta_i^U(\xi_0) \end{array} \right. \text{, or} \left\{ \begin{array}{l} \vartheta_i^L(\tilde{\xi}) \leq \vartheta_i^L(\xi_0) \\ \vartheta_i^U(\tilde{\xi}) < \vartheta_i^U(\xi_0) \end{array} \right. \text{, or} \left\{ \begin{array}{l} \vartheta_i^L(\tilde{\xi}) < \vartheta_i^L(\xi_0) \\ \vartheta_i^U(\tilde{\xi}) < \vartheta_i^U(\xi_0) \end{array} \right. .$$

From the fact $\alpha^L \in R_+^m, \alpha^U \in R_+^m$ with $\sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1$, then above inequalities together yield

$$\sum_{i \in T} \alpha_i^L \vartheta_i^L(\tilde{\xi}) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\tilde{\xi}) < \sum_{i \in T} \alpha_i^L \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\xi_0),$$

which by the pseudoconvexity of $\sum_{i \in T} \alpha_i^L \vartheta_i^L(\cdot) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\cdot)$, we obtain

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\xi_0), \tilde{\xi} - \xi_0 \right\rangle < 0,$$

contradicting to (6). $\qquad\square$

Theorem 3. Let ξ_0 be a strong stationary point of MIVVC. Suppose that $\hat{T}_{0+}^- \cup T_{+0}^+ = \phi$ and τ_i $(i \in T_\tau), \sigma_i$ $(i \in T_\sigma^+), -\sigma_i$ $(i \in T_\sigma^-), \omega_i$ $(i \in T_{+0}^+), -\rho_i$ $(i \in \hat{T}_{0+}^+ \cup \hat{T}_{00}^+ \cup \hat{T}_{0-}^+)$ are quasiconvex functions at ξ_0. If $\sum_{i \in T} \alpha_i^L \vartheta_i^L(\cdot) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\cdot)$ is strictly pseudoconvex function at ξ_0, then ξ_0 is a weakly LU-efficient solution of MIVVC.

Proof. Similar to the proof of Theorem 2, we get

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\xi_0), \xi - \xi_0 \right\rangle$$

$$= \left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\xi_0) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\xi_0) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\xi_0) + \right.$$

$$\left. \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\xi_0), \xi - \xi_0 \right\rangle \geq 0. \tag{7}$$

Reasoning by contraposition, assume that ξ_0 is not a weakly LU-efficient solution. Then there exists a feasible point $\tilde{\xi}$ satisfying

$$\vartheta(\tilde{\xi}) \prec_{LU} \vartheta(\xi_0);$$

that is, for $i \in T$,

$$\begin{cases} \vartheta_i^L(\tilde{\xi}) < \vartheta_i^L(\xi_0), \\ \vartheta_i^U(\tilde{\xi}) < \vartheta_i^U(\xi_0). \end{cases}$$

From the fact that $\alpha^L \in R_+^m, \alpha^U \in R_+^m$ with $\sum\limits_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1$, and by the above inequalities, we get

$$\sum_{i \in T} \alpha_i^L \vartheta_i^L(\tilde{\xi}) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\tilde{\xi}) < \sum_{i \in T} \alpha_i^L \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \vartheta_i^U(\xi_0).$$

By using the strictly pseudoconvexity of $\sum\limits_{i \in T} \alpha_i^L \vartheta_i^L(\cdot) + \sum\limits_{i \in T} \alpha_i^U \vartheta_i^U(\cdot)$ at $\tilde{\xi}$ on $\mathbb{F}_{\mathbb{VC}}$, we get

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\xi_0) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\xi_0), \tilde{\xi} - \xi_0 \right\rangle < 0,$$

contradicting to (7). □

Now, we verify the sufficient optimality conditions by an example.

Example 1. Consider the following multiobjective interval-valued programming problem with vanishing constraints (MIVVC-1):

$$MIVVC - 1 \ \mathbb{R}_+ - \min \ \vartheta(\xi) = (\vartheta_1(\xi), \vartheta_2(\xi))$$
$$= \left([4\xi^2 - \xi, 4\xi^2 + \xi + 1], \ [\xi^2 - 2\xi, \xi^4 + 2\xi] \right)$$
$$\text{subject to}$$
$$\rho_1(\xi) = \xi \geq 0,$$
$$\omega_1(\xi)\rho_1(\xi) = (-1 - \xi)\xi \leq 0,$$

where $\vartheta_1^L(\xi) = 4\xi^2 - \xi, \vartheta_2^L(\xi) = \xi^2 - 2\xi, \vartheta_1^U(\xi) = 4\xi^2 + \xi + 1, \vartheta_2^U(\xi) = \xi^4 + 2\xi$, which is in the form of MIVVC with $m = 2, n = 1, p = q = 0$, and $r = 1$.

The feasible region of MIVVC-1 is $\mathbb{F}_{\mathbb{VC}1} = \{\xi \in R \mid \rho_1(\xi) \geq 0, \ \omega_1(\xi)\rho_1(\xi) \leq 0\}$.
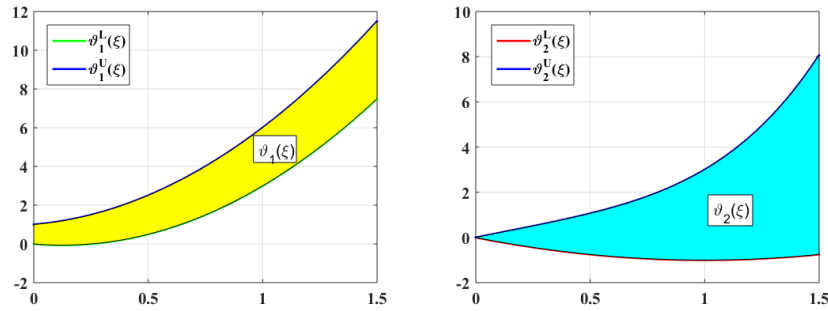
(a) Graphical view of $\vartheta_1(\xi) = [\vartheta_1^L(\xi), \vartheta_1^U(\xi)]$ (b) Graphical view of $\vartheta_2(\xi) = [\vartheta_2^L(\xi), \vartheta_2^U(\xi)]$
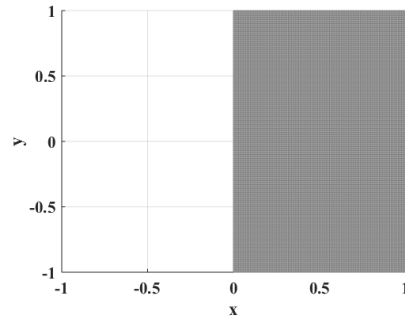
Graphical view of the feasible region of MIVVC-1

Note that $\xi_0 = 0$ is a feasible solution of MIVVC-1. By simple cal-culations, we get $\mathbb{T}(\mathbb{F}_{\mathbb{VC}1}, \xi_0) = \mathbb{F}_{\mathbb{VC}1}$, $\nabla\vartheta_1^L(\xi_0) = \{-1\}$, $\nabla\vartheta_2^L(\xi_0) = \{-2\}$, $\nabla\vartheta_1^U(\xi_0) = \{1\}$, $\nabla\vartheta_2^U(\xi_0) = \{2\}$, $\nabla\rho_1(\xi_0) = \{1\}$, $\nabla\omega_1(\xi_0) = \{-1\}$, $T_+ = T_{0+} = T_{0-} = \phi$, $T_{00} = \{1\}$,

$$\left(\bigcup_{i \in T_{00}} (-\nabla\rho_i(\xi_0))\right)^{-} = \{\xi \in R \mid \xi \geq 1\},$$

$$\left(\bigcup_{i \in T_{00}} (\nabla\omega_i(\xi_0))\right)^{-} = \{\xi \in R \mid \xi \geq 1\},$$

$$\left(\bigcup_{i \in T_{00}} (-\nabla\rho_i(\xi_0))\right)^{-} \cap \left(\bigcup_{i \in T_{00}} \nabla\omega_i(\xi_0)\right)^{-} = \{\xi \in R \mid \xi \geq 1\}.$$

Hence,

$$\left(\bigcup_{i \in T_{00}} (-\nabla \rho_i(\xi_0)) \right)^{-} \cap \left(\bigcup_{i \in T_{00}} (\nabla \omega_i(\xi_0)) \right)^{-} \subset T(\mathbb{F}_{\mathbb{VC}1}, \xi_0),$$

yields that MIVVC-VACQ satisfies at ξ_0. Moreover,

$$\Delta_1 := pos \left(\bigcup_{i \in T_{00}} (-\nabla \rho_i(\xi_0)) \cup \bigcup_{i \in T_{00}} \nabla \omega_i(\xi_0) \right) = \{\xi \in R \mid \xi \geq -1\}$$

is closed. Thus, all assumptions in Theorem 1 are satisfied. Then there exist $\alpha_1^L = \alpha_2^L = \frac{1}{2}, \alpha_1^U = \alpha_2^U = \frac{1}{2}, \lambda_1^\rho = 0, \lambda_1^\omega = 0$ such that (1) is satisfied at $\xi_0 = 0$ for the problem MIVVC-1. Furthermore, it can be easily observed that the hypothesis of Theorem 3 hold at $\xi_0 = 0$, and owing to the fact that for $\xi \neq \xi_0$, $\vartheta(\xi) \nprec_{LU} \vartheta(\xi_0)$. Then, we assert that ξ_0 is a locally weakly LU-efficient solution of MIVVC-1.

4 The Wolfe type duality

In this section, we present the Wolfe type dual problem to MIVVC assuming that all the functions to be convex. For a given $\bar{u}$, $\Theta(\bar{u})$ is the system of the neighborhoods of $\bar{u}$. For $\xi_0 \in \mathbb{F}_{\mathbb{VC}}$, $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i \in T} (\alpha_i^L + \alpha_i^U) = 1, \lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0$, and $\lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0$, we define

$$\mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) = \left(\vartheta_1(u) + \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(u) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(u) \right. \right.$$

$$\left. - \sum_{i \in T_r} \lambda_i^\rho \rho_i(u) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(u) \right) e + \cdots$$

$$+ \vartheta_m(u) + \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(u) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(u) - \right.$$

$$\left. \left. \sum_{i \in T_r} \lambda_i^\rho \rho_i(u) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(u) \right) e \right),$$

where $e := (1, \ldots, 1) \in R^m$. We consider the Wolfe type dual problem as follows:

$(WD_w(\xi_0))$ $R_+^m - \max \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho)$
         subject to
$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(u) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(u) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(u)$$

$$+ \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(u) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(u) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(u) = 0,$$

$$\sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1, \lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0 \text{ and}$$

$$\lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0, (u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in$$
$$R^n \times R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r.$$

The feasible set of $(WD_w(\xi_0))$ is defined by

$$\mathbb{F}_{\mathbb{VC}w}(\xi_0) := \left\{ (u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R^p \times R^q \times R^r \right.$$

$$\times R^r | \sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1, \lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0, \text{ and}$$

$$\lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0, \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(u) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(u) +$$

$$\sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(u) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(u) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(u) +$$

$$\left. \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(u) = 0 \right\}.$$

The Wolfe type duality problem of MIVVC, which is not dependent on ξ_0, is

$(WD_w):$ $\qquad R_+^m - \max \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho)$
$\qquad\qquad$ subject to
$\qquad\qquad (\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w} := \bigcap_{\xi_0 \in \mathbb{F}_{\mathbb{VC}}} \mathbb{F}_{\mathbb{VC}w}(\xi_0).$

Definition 8. Let $\xi_0 \in \mathbb{F}_{\mathbb{VC}}$. Then $(\bar{u}, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in \mathbb{F}_{\mathbb{VC}w}(\xi_0)$ is a locally LU-efficient solution of $(WD_w(\xi_0))$ (locally weakly LU-efficient solution of $(WD_w(\xi_0))$) if there exists $U \in \Theta(\bar{u})$ such that there is no $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w}(\xi_0) \cap U$ satisfying

$$\mathcal{L}(\bar{u}, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \preceq_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho),$$
$$\left(\mathcal{L}(\bar{u}, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \prec_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right).$$

Theorem 4 (Weak Duality). Let $\xi \in \mathbb{F}_{\mathbb{VC}}$ and let $(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w}$. Suppose that $\tau_i(i \in T_\tau^+(\xi)), \sigma_i(i \in T_\sigma^+(\xi)), -\sigma_i(i \in T_\sigma^-(\xi)), \rho_i(i \in \hat{T}_0^-(\xi)), -\rho_i(i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi)), \omega_i(i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi)), -\omega_i(i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi))$ are convex functions at ψ,

(i) If $\vartheta_i^L, \vartheta_i^U (i \in T)$ are convex functions at ψ, then

$$\vartheta(\xi) \nprec_{LU} \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho).$$

(ii) If $\vartheta_i^L, \vartheta_i^U (i \in T)$ are strictly convex functions at ψ, then

$$\vartheta(\xi) \npreceq_{LU} \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho).$$

Proof. For $\xi \in \mathbb{F}_{\mathbb{VC}}$ and $(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w} = \bigcap\limits_{\xi_0 \in \mathbb{F}_{\mathbb{VC}}} \mathbb{F}_{\mathbb{VC}w}(\xi_0)$, one gets

$$\tau_i(\xi) \leq 0 \ (i \in T_\tau), \sigma_i(\xi) = 0 \ (i \in T_\sigma), \rho_i(\xi) \geq 0 \ (i \in T_r), \omega_i(\xi)\rho_i(\xi) \leq 0 \ (i \in T_r) \tag{8}$$

and

$$\sum_{i\in T} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i\in T} \alpha_i^U \nabla \vartheta_i^U(\psi) + \sum_{i\in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi)$$

$$+ \sum_{i\in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi) - \sum_{i\in T_r} \lambda_i^\rho \nabla \rho_i(\psi) + \sum_{i\in T_r} \lambda_i^\omega \nabla \omega_i(\psi) = 0 \tag{9}$$

with

$$\sum_{i\in T} \left(\alpha_i^L + \alpha_i^U \right) = 1, \lambda_{T_+(\xi)}^\rho \geq 0, \lambda_{T_{0+}(\xi)}^\omega \leq 0, \lambda_{T_{+-}(\xi)\cup T_{0-}(\xi)}^\omega \geq 0. \tag{10}$$

Therefore we conclude from (8), based on the convexity of τ_i $(i \in T_\tau^+(\xi))$, σ_i $(i \in T_\sigma^+(\xi))$, $-\sigma_i$ $(i \in T_\sigma^-(\xi))$, ρ_i $(i \in \hat{T}_0^-(\xi))$, $-\rho_i$ $(i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi))$, ω_i $(i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi))$, $-\omega_i$ $(i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi))$ at ψ and by the definitions of index sets that

$$\tau_i(\psi) + \langle \nabla \tau_i(\psi), \xi - \psi \rangle \leq \tau_i(\xi) \leq 0, \lambda_i^\tau > 0, \text{ for all } i \in T_\tau^+(\xi),$$

$$\sigma_i(\psi) + \langle \nabla \sigma_i(\psi), \xi - \psi \rangle \leq \sigma_i(\xi) = 0, \lambda_i^\sigma > 0, \text{ for all } i \in T_\sigma^+(\xi),$$

$$-\sigma_i(\psi) + \langle -\nabla \sigma_i(\psi), \xi - \psi \rangle \leq -\sigma_i(\xi) = 0, \lambda_i^\sigma < 0, \text{ for all } i \in T_\sigma^-(\xi),$$

$$\rho_i(\psi) + \langle \nabla \rho_i(\psi), \xi - \psi \rangle \leq \rho_i(\xi) = 0, \lambda_i^\rho < 0, \text{ for all } i \in \hat{T}_0^-(\xi),$$

$$-\rho_i(\psi) + \langle -\nabla \rho_i(\psi), \xi - \psi \rangle \leq -\rho_i(\xi) < 0, \lambda_i^\rho > 0, \text{ for all } i \in \hat{T}_+^+(\xi),$$

$$-\rho_i(\psi) + \langle -\nabla \rho_i(\psi), \xi - \psi \rangle \leq -\rho_i(\xi) < 0, \lambda_i^\rho > 0, \text{ for all } i \in \hat{T}_0^+(\xi),$$

$$\omega_i(\psi) + \langle \nabla \omega_i(\psi), \xi - \psi \rangle \leq \omega_i(\xi) = 0, \lambda_i^\omega > 0, \text{ for all } i \in T_{+0}^+(\xi) \cup T_{00}^+(\xi),$$

$$\omega_i(\psi) + \langle \nabla \omega_i(\psi), \xi - \psi \rangle \leq \omega_i(\xi) < 0, \lambda_i^\omega > 0, \text{ for all } i \in T_{+-}^+(\xi) \cup T_{0-}^+(\xi),$$

$$-\omega_i(\psi) + \langle -\nabla \omega_i(\psi), \xi - \psi \rangle \leq -\omega_i(\xi) = 0, \lambda_i^\omega > 0, \text{ for all } i \in T_{+0}^-(\xi) \cup T_{00}^-(\xi),$$

$$-\omega_i(\psi) + \langle -\nabla \omega_i(\psi), \xi - \psi \rangle \leq -\omega_i(\xi) < 0, \lambda_i^\omega < 0, \text{ for all } i \in T_{0+}^-(\xi).$$

The above inequalities imply that

$$\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi)$$

$$+ \left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\psi) \right.$$

$$\left. + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\psi), \xi - \psi \right\rangle \le 0. \tag{11}$$

By using (9) and (11), we obtain

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle$$

$$= - \left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\psi), \xi - \psi \right\rangle$$

$$\ge \sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi). \tag{12}$$

(i) Suppose to the contrary that

$$\vartheta(\xi) \prec_{LU} \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho). \tag{13}$$

Then, we deduce from (13) and $\alpha^L \in R_+^m, \alpha^U \in R_+^m$ that

$$\left\langle \alpha^L, \vartheta^L(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0,$$
$$\left\langle \alpha^U, \vartheta^U(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0,$$

which is equivalent to

$$\sum_{i=1}^m \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right) - \sum_{i=1}^m \alpha_i^L \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) \right.$$

$$\left. - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right) < 0,$$

$$\sum_{i=1}^m \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right) - \sum_{i=1}^m \alpha_i^U \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) \right.$$

$$\left. - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right) < 0.$$

On adding, we have

$$\sum_{i=1}^m \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right) + \sum_{i=1}^m \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right) - \sum_{i=1}^m \left(\alpha_i^L + \alpha_i^U \right)$$

$$\left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right) < 0.$$

It follows from $\sum_{i=1}^{m} \left(\alpha_i^L + \alpha_i^U \right) = 1$ that

$$\sum_{i=1}^{m} \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right) + \sum_{i=1}^{m} \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right)$$

$$< \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right). \qquad (14)$$

From the convexity of $\vartheta_i^L, \vartheta_i^U (i \in T)$ at ψ, we get

$$\begin{aligned}
\left\langle \nabla \vartheta_i^L(\psi), \xi - \psi \right\rangle &\leq \vartheta_i^L(\xi) - \vartheta_i^L(\psi), \quad \text{for all } i \in T, \\
\left\langle \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle &\leq \vartheta_i^U(\xi) - \vartheta_i^U(\psi), \quad \text{for all } i \in T,
\end{aligned}$$

which leads that

$$\left\langle \sum_{i=1}^{m} \alpha_i^L \nabla \vartheta_i^L(\psi), \xi - \psi \right\rangle \leq \sum_{i=1}^{m} \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right),$$

$$\left\langle \sum_{i=1}^{m} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle \leq \sum_{i=1}^{m} \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right). \qquad (15)$$

We deduce from the above inequalities and (14) that

$$\left\langle \sum_{i=1}^{m} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i=1}^{m} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle$$

$$< \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right),$$

which contradicts with (12).

(ii) Reasoning by contraposition, suppose that

$$\vartheta(\xi) \preceq_{LU} \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho). \qquad (16)$$

We deduce from (16) and $\alpha^L \in R_+^m, \alpha^U \in R_+^m$ that

$$\begin{cases}
\left\langle \alpha^L, \vartheta^L(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0, \\
\left\langle \alpha^U, \vartheta^U(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle \leq 0,
\end{cases}$$

or

$$
\begin{cases}
\left\langle \alpha^L, \vartheta^L(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle \le 0, \\
\left\langle \alpha^U, \vartheta^U(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0,
\end{cases}
$$

or

$$
\begin{cases}
\left\langle \alpha^L, \vartheta^L(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0, \\
\left\langle \alpha^U, \vartheta^U(\xi) - \mathcal{L}(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \right\rangle < 0,
\end{cases}
$$

which is equivalent to

$$
\sum_{i=1}^{m} \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right) + \sum_{i=1}^{m} \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right)
$$

$$
\le \sum_{i=1}^{m} \left(\alpha_i^L + \alpha_i^U \right) \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right).
$$

It follows from $\sum_{i=1}^{m} \left(\alpha_i^L + \alpha_i^U \right) = 1$ that

$$
\sum_{i=1}^{m} \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right) + \sum_{i=1}^{m} \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right)
$$

$$
\le \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right). \qquad (17)
$$

From the strict convexity of $\vartheta_i^L, \vartheta_i^U (i \in T)$ at ψ, we get

$$
\begin{aligned}
\left\langle \nabla \vartheta_i^L(\psi), \xi - \psi \right\rangle &< \vartheta_i^L(\xi) - \vartheta_i^L(\psi), && \text{for all } i \in T \\
\left\langle \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle &< \vartheta_i^U(\xi) - \vartheta_i^U(\psi), && \text{for all } i \in T,
\end{aligned}
$$

which leads that

$$
\left\langle \sum_{i=1}^{m} \alpha_i^L \nabla \vartheta_i^L(\psi), \xi - \psi \right\rangle < \sum_{i=1}^{m} \alpha_i^L \left(\vartheta_i^L(\xi) - \vartheta_i^L(\psi) \right),
$$

$$
\left\langle \sum_{i=1}^{m} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle < \sum_{i=1}^{m} \alpha_i^U \left(\vartheta_i^U(\xi) - \vartheta_i^U(\psi) \right). \qquad (18)
$$

It follows from (17) and (18) that

$$
\left\langle \sum_{i=1}^{m} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i=1}^{m} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle
$$

$$
< \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\psi) \right),
$$

contracting to (12). $\square$

Example 2. Consider the following multiobjective interval-valued programming problem with vanishing constraints (MIVVC-2):

$$MIVVC - 2 \qquad \mathbb{R}_+ - \min \ \vartheta(\xi) = (\vartheta_1(\xi), \vartheta_2(\xi))$$
$$= \left([2\xi + 4, e^{2\xi}], \ [-2\xi + 1, -\xi - 1]\right)$$
$$\text{subject to}$$
$$\rho_1(\xi) = \xi \geq 0,$$
$$\omega_1(\xi)\rho_1(\xi) = -e^{1-\xi}\xi \leq 0,$$

where $\vartheta_1^L(\xi) = 2\xi + 4, \vartheta_2^L(\xi) = -2\xi + 1, \vartheta_1^U(\xi) = e^{2\xi}, \vartheta_2^U(\xi) = -\xi - 1$, which is in the form of MIVVC with $m = n = 1$, $p = q = 0$ and $r = 1$. The feasible set of MIVVC-2 is $\mathbb{F}_{\mathbb{VC}2} = \{\xi \in R \mid \rho_1(\xi) \geq 0, \ \omega_1(\xi)\rho_1(\xi) \leq 0\}$. For any $\xi_0 \in \mathbb{F}_{\mathbb{VC}2}$, the corresponding Wolfe type dual problem to MIVVC-2 is given by

$$(WD_w(\xi_0) - 1)R_+^m - \max \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\omega, \lambda^\rho)$$
$$= \left([2u + 4, e^{2u}] + (-\lambda_1^\rho(u) + \lambda_1^\omega(-e^{1-u}))(1),\right.$$
$$\left.[-2u + 1, -u - 1] + (-\lambda_1^\rho(u) + \lambda_1^\omega(-e^{1-u}))(1)\right)$$
$$\text{subject to}$$
$$\alpha_1^L(2) + \alpha_1^U(2e^{2u}) + \alpha_2^L(-2) + \alpha_2^U(-1) - \lambda_1^\rho(1)$$
$$+ \lambda_1^\omega(-1) = 0,$$
$$\alpha_1^L + \alpha_1^U = 1, \alpha_2^L + \alpha_2^U = 1, \lambda_1^\rho \begin{cases} \geq 0, \ if 1 \in T_+(\xi_0), \\ \in R, \ if 1 \in T_0(\xi_0), \end{cases}$$
$$\lambda_1^\omega \begin{cases} \leq 0, \ if 1 \in T_{0+}(\xi_0), \\ \geq 0, \ if 1 \in T_{+-}(\xi_0) \cup T_{0-}(\xi_0), \\ \in R, \ if 1 \in T_{+0}(\xi_0) \cup T_{00}(\xi_0), \end{cases}$$
$$where \ (u, \alpha_1^L, \alpha_1^U, \alpha_2^L, \alpha_2^U, \lambda^\omega, \lambda^\rho) \in R \times R_+ \times R_+ \times R_+ \times R_+ \times R \times R.$$

Therefore, we get the following feasible set of problem $(WD_w(\xi_0) - 1)$:

$$(\mathbb{F}_{\mathbb{VC}w}(\xi_0) - 1) := \left\{(u, \alpha_1^L, \alpha_1^U, \alpha_2^L, \alpha_2^U, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \right.$$
$$\times R_+^m \times R_+^m \times R^r \times R^r | \alpha_1^L + \alpha_1^U = 1, \alpha_2^L + \alpha_2^U = 1,$$
$$\lambda_1^\rho \in R, \lambda_1^\omega \in R, \alpha_1^L \nabla \vartheta_1^L(u) + \alpha_1^U \nabla \vartheta_1^U(u) + \alpha_2^L \nabla \vartheta_2^L(u)$$
$$\left. + \alpha_2^U \nabla \vartheta_2^U(u) - \lambda_1^\rho \nabla \rho_1(u) + \lambda_1^\omega \nabla \omega_1(u) = 0 \right\}.$$

By elementary calculations, we get $\nabla\vartheta_1^L(\xi_0) = \{2\}$, $\nabla\vartheta_1^U(\xi_0) = \{2\}$, $\nabla\vartheta_2^L(\xi_0) = \{-2\}$, $\nabla\vartheta_2^U(\xi_0) = \{-1\}$, $\nabla\rho_1(\xi_0) = \{1\}$, $\nabla\omega_1(\xi_0) = \{e\}$, $T_+ = T_{0+} = T_{0-} = \phi$, $T_{00} = \{1\}$.

Clearly, $(u, \alpha_1^L, \alpha_1^U, \alpha_2^L, \alpha_2^U, \lambda^\omega, \lambda^\rho) = (0, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, \frac{1}{2}, 0, \frac{1}{2})$ is a feasible solution to $(WD_w(\xi_0) - 1)$. We also note that $\xi_0 = 0$ is a feasible solution to MIVVC-2. On the other hand, it is easily verified that the hypothesis (i) and (ii) of Theorem 4 are satisfied at $u = 0$.

Theorem 5 (Strong duality). Let $\xi_0 \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$ be a locally weakly efficient solution of MIVVC. If MIVVC-VACQ holds at ξ_0 and the set Δ_1 is closed, then there exists $(\bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\bar\lambda^\rho_{T_+(\xi_0)} = 0, \bar\lambda^\rho_{T_{00}(\xi_0) \cup T_{0-}(\xi_0)} \geq 0, \bar\lambda^\omega_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)} = 0$ and $\bar\lambda^\omega_{T_{+0}(\xi_0) \cup T_{00}(\xi_0)} \geq 0$ such that $(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}w}(\xi_0)$ and $\vartheta(\xi_0) = \mathcal{L}(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho)$. Furthermore, assume that $\tau_i(i \in T_\tau^+(\xi_0)), \sigma_i$ $(i \in T_\sigma^+(\xi_0)), -\sigma_i(i \in T_\sigma^-(\xi_0)), \rho_i(i \in \hat{T}_0^-(\xi_0)), -\rho_i(i \in \hat{T}_+^+(\xi_0) \cup \hat{T}_0^+(\xi_0)), \omega_i(i \in T_{+0}^+(\xi_0) \cup T_{+-}^+(\xi_0) \cup T_{00}^+(\xi_0) \cup T_{0-}^+(\xi_0)), -\omega_i(i \in T_{+0}^-(\xi_0) \cup T_{0+}^-(\xi_0) \cup T_{00}^-(\xi_0))$ are convex functions at ξ_0.

(i) If $\vartheta_i^L, \vartheta_i^U(i \in T)$ are convex functions at ξ_0, then $(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho)$ is a weakly LU-efficient solution of $WD_w(\xi_0)$.

(ii) If $\vartheta_i^L, \vartheta_i^U(i \in T)$ are strictly convex functions at ξ_0, then $(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho)$ is an LU-efficient solution of $WD_w(\xi_0)$.

Proof. In view of Theorem 1, there exists $(\bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\bar\lambda^\rho_{T_+(\xi_0)} = 0, \bar\lambda^\rho_{T_{00}(\xi_0) \cup T_{0-}(\xi_0)} \geq 0$, $\bar\lambda^\omega_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)} = 0$ and $\bar\lambda^\omega_{T_{+0}(\xi_0) \cup T_{00}(\xi_0)} \geq 0$ such that

$$\sum_{i \in T} \bar\alpha_i^L \nabla\vartheta_i^L(\xi_0) + \sum_{i \in T} \bar\alpha_i^U \nabla\vartheta_i^U(\xi_0) + \sum_{i \in T_\tau} \bar\lambda_i^\tau \nabla\tau_i(\xi_0) + \sum_{i \in T_\sigma} \bar\lambda_i^\sigma \nabla\sigma_i(\xi_0)$$

$$- \sum_{i \in T_r} \bar\lambda_i^\rho \nabla\rho_i(\xi_0) + \sum_{i \in T_r} \bar\lambda_i^\omega \nabla\omega_i(\xi_0) = 0.$$

Since $\bar\lambda^\tau \in R^p$, one has $\bar\lambda_i^\tau \tau_i(\xi_0) = 0$ for all $i \in T_\tau$, and thus, $\sum_{i \in T_\tau} \bar\lambda_i^\tau \tau_i(\xi_0) = 0$. The fact $\xi_0 \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$ guarantees that $\sum_{i \in T_\sigma} \bar\lambda_i^\sigma \sigma_i(\xi_0) = 0$. Moreover, we observe by $\bar\lambda^\rho_{T_+(\xi_0)} = 0$ and $\rho_i(\xi_0) = 0$ for all $i \in T_0(\xi_0)$ that $\sum_{i \in T_r} \bar\lambda_i^\rho \rho_i(\xi_0) = 0$. Analogously, as $\bar\lambda^\omega_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)} = 0$ and $\omega_i(\xi_0) = 0$ for all $i \in T_{+0}(\xi_0) \cup T_{00}(\xi_0)$, we know that $\sum_{i \in T_r} \bar\lambda_i^\omega \omega_i(\xi_0) = 0$. Thus, $(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}w}(\xi_0)$ and $\sum_{i \in T_\tau} \bar\lambda_i^\tau \tau_i(\xi_0) + \sum_{i \in T_\sigma} \bar\lambda_i^\sigma \sigma_i(\xi_0) - \sum_{i \in T_r} \bar\lambda_i^\rho \rho_i(\xi_0) + \sum_{i \in T_r} \bar\lambda_i^\omega \omega_i(\xi_0) = 0$ which is nothing else but the following equality $\vartheta(\xi_0) = \mathcal{L}(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho)$.

(i). Now, arguing by contradiction, let us suppose that $(\xi_0, \bar\alpha^L, \bar\alpha^U, \bar\lambda^\tau, \bar\lambda^\sigma, \bar\lambda^\omega, \bar\lambda^\rho)$ is not a weakly LU-efficient solution of $WD_w(\xi_0)$. By the definition, there

exists $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w}(\xi_0)$ such that

$$\mathcal{L}(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \prec_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho).$$

This shows that $\vartheta(\xi_0) \prec_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho)$, which contradicts with Theorem 4(i).

(ii). Reasoning to the contrary, let us assume that $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho)$ is not an LU-efficient solution of $WD_w(\xi_0)$. Then it guarantees the existence of $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}w}(\xi_0)$ such that

$$\mathcal{L}(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \preceq_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho).$$

Consequently, $\vartheta(\xi_0) \preceq_{LU} \mathcal{L}(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho)$ which contradicts with Theorem 4(ii). $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ $\square$

Theorem 6 (Strict converse duality). Let $\tilde{\xi} \in \mathbb{F}_{\mathbb{VC}}$ be a locally weakly efficient solution of MIVVC such that MIVVC-VACQ holds at $\tilde{\xi}$ and the strong duality between the MIVVC and the $(WD_W(\tilde{\xi}))$ as in Theorem 5 holds. Also, let $(\tilde{\psi}, \tilde{\alpha}^L, \tilde{\alpha}^U, \tilde{\lambda}^\tau, \tilde{\lambda}^\sigma, \tilde{\lambda}^\omega, \tilde{\lambda}^\rho) \in \mathbb{F}_{\mathbb{VC}w}$ be an LU-efficient solution of $(WD_W(\tilde{\xi}))$. Moreover, Assume that $\vartheta_i^L, \vartheta_i^U (i \in T)$ are strictly convex functions and that $\tau_i (i \in T_\tau^+(\tilde{\xi})), \sigma_i (i \in T_\sigma^+(\tilde{\xi})), -\sigma_i (i \in T_\sigma^-(\tilde{\xi})), \rho_i (i \in \hat{T}_0^-(\tilde{\xi})), -\rho_i (i \in \hat{T}_+^+(\tilde{\xi}) \cup \hat{T}_0^+(\tilde{\xi})), \omega_i (i \in T_{+0}^+(\tilde{\xi}) \cup T_{+-}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi})), -\omega_i (i \in T_{+0}^-(\tilde{\xi}) \cup T_{0+}^-(\tilde{\xi}) \cup T_{00}^-(\tilde{\xi}))$ are convex functions at $\tilde{\psi}$, respectively. Then, $\tilde{\xi} = \tilde{\psi}$.

Proof. Suppose on the contrary, $\tilde{\xi} \neq \tilde{\psi}$. Then, by Theorem 5, there exist $\tilde{\xi} \in \mathbb{F}_{\mathbb{VC}}$ and $(\tilde{\psi}, \tilde{\alpha}^L, \tilde{\alpha}^U, \tilde{\lambda}^\tau, \tilde{\lambda}^\sigma, \tilde{\lambda}^\omega, \tilde{\lambda}^\rho) \in \mathbb{F}_{\mathbb{VC}w}$, and hence

$$\vartheta(\tilde{\xi}) = \mathcal{L}(\tilde{\psi}, \tilde{\alpha}^L, \tilde{\alpha}^U, \tilde{\lambda}^\tau, \tilde{\lambda}^\sigma, \tilde{\lambda}^\omega, \tilde{\lambda}^\rho). \tag{19}$$

The strict convexity of $\vartheta_i^L, \vartheta_i^U (i \in T)$ at $\tilde{\psi}$ gives that

$$\left\langle \sum_{i=1}^m \alpha_i^L \nabla \vartheta_i^L(\tilde{\psi}) + \sum_{i=1}^m \alpha_i^U \nabla \vartheta_i^U(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle$$

$$< \left(\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\tilde{\psi}) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\tilde{\psi}) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\tilde{\psi}) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\tilde{\psi}) \right). \tag{20}$$

The convexity of $\tau_i (i \in T_\tau^+(\tilde{\xi})), \sigma_i (i \in T_\sigma^+(\tilde{\xi})), -\sigma_i (i \in T_\sigma^-(\tilde{\xi})),$ $\rho_i (i \in \hat{T}_0^+(\tilde{\xi})), -\rho_i (i \in \hat{T}_+^+(\tilde{\xi}) \cup \hat{T}_0^+(\tilde{\xi})), \omega_i (i \in T_{+0}^+(\tilde{\xi}) \cup T_{+-}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi})), -\omega_i (i \in T_{+0}^-(\tilde{\xi}) \cup T_{0+}^-(\tilde{\xi}) \cup T_{00}^-(\tilde{\xi}))$ at $\tilde{\psi}$ and by the definitions of index sets imply that

$$\tau_i(\tilde{\psi}) + \left\langle \nabla \tau_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \le \tau_i(\tilde{\xi}) = 0, \lambda_i^\tau > 0, \text{ for all } i \in T_\tau^+(\tilde{\xi}),$$

$$\sigma_i(\tilde{\psi}) + \left\langle \nabla \sigma_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \le \sigma_i(\tilde{\xi}) = 0, \lambda_i^\sigma > 0, \text{ for all } i \in T_\sigma^+(\tilde{\xi}),$$

$$-\sigma_i(\tilde{\psi}) + \left\langle -\nabla\sigma_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq -\sigma_i(\tilde{\xi}) = 0, \lambda_i^\sigma < 0, \text{ for all } i \in T_\sigma^-(\tilde{\xi}),$$

$$\rho_i(\tilde{\psi}) + \left\langle \nabla\rho_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq \rho_i(\tilde{\xi}) = 0, \lambda_i^\rho < 0, \text{ for all } i \in \hat{T}_0^-(\tilde{\xi}),$$

$$-\rho_i(\tilde{\psi}) + \left\langle -\nabla\rho_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq -\rho_i(\tilde{\xi}) < 0, \lambda_i^\rho > 0, \text{ for all } i \in \hat{T}_+^+(\tilde{\xi}),$$

$$-\rho_i(\tilde{\psi}) + \left\langle -\nabla\rho_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq -\rho_i(\tilde{\xi}) < 0, \lambda_i^\rho > 0, \text{ for all } i \in \hat{T}_0^+(\tilde{\xi}),$$

$$\omega_i(\tilde{\psi}) + \left\langle \nabla\omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq \omega_i(\tilde{\xi}) = 0, \lambda_i^\omega > 0, \text{ for all } i \in T_{+0}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}),$$

$$\omega_i(\tilde{\psi}) + \left\langle \nabla\omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq \omega_i(\tilde{\xi}) < 0, \lambda_i^\omega > 0, \text{ for all } i \in T_{+-}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi}),$$

which implies that

$$\sum_{i \in T_\tau} \lambda_i^\tau \tau_i(\tilde{\xi}) + \sum_{i \in T_\sigma} \lambda_i^\sigma \sigma_i(\tilde{\xi}) - \sum_{i \in T_r} \lambda_i^\rho \rho_i(\tilde{\xi}) + \sum_{i \in T_r} \lambda_i^\omega \omega_i(\tilde{\xi}) + \left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla\tau_i(\tilde{\psi}) \right.$$

$$\left. + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla\sigma_i(\tilde{\psi}) - \sum_{i \in T_r} \lambda_i^\rho \nabla\rho_i(\tilde{\psi}) + \sum_{i \in T_r} \lambda_i^\omega \nabla\omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0. \quad (21)$$

On adding the inequalities (20) and (21) and by using the duality constraint (9) of $(WD_w(\tilde{\xi}))$, we have

$$\mathcal{L}(\tilde{\psi}, \tilde{\alpha}^L, \tilde{\alpha}^U, \tilde{\lambda}^\tau, \tilde{\lambda}^\sigma, \tilde{\lambda}^\omega, \tilde{\lambda}^\rho) \prec_{LU} \vartheta(\tilde{\xi}),$$

which contradicts with (19). $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\square$

5 The Mond–Weir type duality

The Wolfe dual of the primal problem, which we discussed in the last section, says that all functions must be convex. Wolfe duality does not work for functions, where the objective function is only pseudoconvex and the constraints are only quasiconvex in the primal problem MIVVC (see, Mond [24]). So, in this section, we propose a Mond–Weir type dual to the primal problem MIVVC to weaken the convexity assumptions.

Consider $\xi_0 \in \mathbb{F}_{\mathbb{VC}}, (u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i \in T} (\alpha_i^L + \alpha_i^U) = 1, \lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0,$ and $\lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0.$ We consider the Mond–Weir type dual problem as follows:

$(MWD_M(\xi_0))\ R_+^m - \max\ \vartheta(u)$
$\qquad\qquad$ subject to

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(u) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(u) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(u) +$$

$$\sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(u) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(u) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(u) = 0,$$

$$\lambda_i^\tau \tau_i(u) \geq 0 \ (i \in T_\tau), \lambda_i^\sigma \sigma_i(u) = 0 \ (i \in T_\sigma), -\lambda_i^\rho \rho_i(u) \geq 0$$

$$(i \in T_r), \lambda_i^\omega \omega_i(u) \geq 0 \ (i \in T_r), \sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1,$$

$$\lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0 \text{ and } \lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0, (u, \alpha^L, \alpha^U,$$

$$\lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r.$$

The feasible set of $(MWD_M(\xi_0))$ is defined by

$$\mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0) := \Bigg\{ (u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R^p \times R^q$$

$$\times R^r \times R^r \mid \lambda_i^\tau \tau_i(u) \geq 0 \ (i \in T_\tau), \lambda_i^\sigma \sigma_i(u) = 0 \ (i \in T_\sigma),$$

$$- \lambda_i^\rho \rho_i(u) \geq 0 \ (i \in T_r), \lambda_i^\omega \omega_i(u) \geq 0 \ (i \in T_r),$$

$$\sum_{i \in T} \left(\alpha_i^L + \alpha_i^U \right) = 1, \lambda_{T_+(\xi_0)}^\rho \geq 0, \lambda_{T_{0+}(\xi_0)}^\omega \leq 0, \text{ and}$$

$$\lambda_{T_{+-}(\xi_0) \cup T_{0-}(\xi_0)}^\omega \geq 0, \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(u) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(u)$$

$$+ \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(u) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(u) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(u)$$

$$+ \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(u) = 0 \Bigg\}.$$

Furthermore, let us denote by Γ_M the projection of $\mathbb{F}_{\mathbb{V}\mathbb{C}M}$ on $\mathbb{R}^n$; that is,

$$\Gamma_M(\xi_0) := \left\{ u \in \mathbb{R}^n | (u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \Gamma_M(\xi_0) \right\}.$$

The other Mond–Weir type duality problem of MIVVC, which is not dependent on ξ_0, is

$$(MWD_M): \qquad R_+^m - \max \ \vartheta(\psi)$$

$$\text{subject to}$$

$$(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \Gamma_M := \bigcap_{\xi_0 \in \Gamma} \Gamma_M(\xi_0).$$

Definition 9. Let $\xi_0 \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$. Then $(\bar{u}, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0)$ is a locally LU-efficient solution of $(MWD_M(\xi_0))$ (locally weakly LU-efficient solution of $(MWD_M(\xi_0))$) if there exists $U \in \Theta(\bar{u})$ such that there is no $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0) \cap U$ satisfying

$$\vartheta(\bar{u}) \preceq_{LU} \vartheta(u)$$
$$(\vartheta(\bar{u}) \prec_{LU} \vartheta(u))$$

Theorem 7 (Weak duality). Let $\xi \in \mathbb{F}_{\mathbb{VC}}$ and $(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}M}$. Suppose that τ_i $(i \in T_\tau^+(\xi)), \sigma_i$ $(i \in T_\sigma^+(\xi)), -\sigma_i$ $(i \in T_\sigma^-(\xi)), \rho_i$ $(i \in \hat{T}_0^-(\xi)), -\rho_i$ $(i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi)), \omega_i$ $(i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi)), -\omega_i$ $(i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi))$ are quasiconvex functions at ψ on $\mathbb{F}_{\mathbb{VC}M} \cup \Gamma_M$. If $\vartheta_i^L, \vartheta_i^U (i \in T)$ are strictly pseudoconvex functions at ψ on $\mathbb{F}_{\mathbb{VC}M} \cup \Gamma_M$, then $\vartheta(\xi) \npreceq_{LU} \vartheta(\psi)$.

Proof. For $\xi \in \mathbb{F}_{\mathbb{VC}M}$ and

$$(\psi, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{VC}M} = \bigcap_{\xi_0 \in \mathbb{F}_{\mathbb{VC}M}} \mathbb{F}_{\mathbb{VC}M}(\xi_0),$$

we have

$$\tau_i(\xi) \le 0 \ (i \in T_\tau), \quad \sigma_i(\xi) = 0 \ (i \in T_\sigma), \quad \rho_i(\xi) \ge 0 \ (i \in T_r), \quad \omega_i(\xi)\rho_i(\xi) \le 0 \ (i \in T_r), \tag{22}$$

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\psi) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi)$$

$$- \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\psi) = 0, \tag{23}$$

and

$$\lambda_i^\tau \tau_i(\psi) \ge 0 \ (i \in T_\tau), \quad \lambda_i^\sigma \sigma_i(\psi) = 0 \ (i \in T_\sigma),$$
$$-\lambda_i^\rho \rho_i(\psi) \ge 0 \ (i \in T_r), \quad \lambda_i^\omega \omega_i(\psi) \ge 0 \ (i \in T_r), \tag{24}$$

with

$$\sum_{i \in T} \left(\alpha_i^L + \alpha_i^U\right) = 1, \quad \lambda_{T_+(\xi)}^\rho \ge 0, \quad \lambda_{T_{0+}(\xi)}^\omega \le 0, \quad \lambda_{T_{+-}(\xi) \cup T_{0-}(\xi)}^\omega \ge 0. \tag{25}$$

It follows from the above inequalities that

$$\tau_i(\xi) \le 0 \le \tau_i(\psi) \le 0, \quad \text{for all } i \in T_\tau^+(\xi),$$

$$\sigma_i(\xi) = \sigma_i(\psi) = 0, \quad \text{for all } i \in T_\sigma^+(\xi) \cup T_\sigma^-(\xi),$$

$$\rho_i(\xi) = 0 \le \rho_i(\psi), \quad \text{for all } i \in \hat{T}_0^-(\xi),$$

$$-\rho_i(\xi) \le 0 \le -\rho_i(\psi), \quad \text{for all } i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi),$$

$$\omega_i(\xi) \le 0 \le \omega_i(\psi), \quad \text{for all } i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi),$$

$$-\omega_i(\xi) \le 0 \le -\omega_i(\psi) = 0, \quad \text{for all } i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi).$$

Thus, we deduce from the quasiconvexity of τ_i $(i \in T_\tau^+(\xi)), \sigma_i$ $(i \in T_\sigma^+(\xi)), -\sigma_i$ $(i \in T_\sigma^-(\xi)), \rho_i$ $(i \in \hat{T}_0^-(\xi)), -\rho_i$ $(i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi)),$

ω_i $(i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi))$, $-\omega_i$ $(i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi))$ at ψ and the definitions of index sets that

$$\langle \nabla \tau_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\tau > 0, \quad \text{for all } i \in T_\tau^+(\xi),$$

$$\langle \nabla \sigma_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\sigma > 0, \quad \text{for all } i \in T_\sigma^+(\xi),$$

$$\langle -\nabla \sigma_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\sigma < 0, \quad \text{for all } i \in T_\sigma^-(\xi),$$

$$\langle \nabla \rho_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\rho < 0, \quad \text{for all } i \in \hat{T}_0^-(\xi),$$

$$\langle -\nabla \rho_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\rho > 0, \quad \text{for all } i \in \hat{T}_+^+(\xi) \cup \hat{T}_0^+(\xi),$$

$$\langle \nabla \omega_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\omega > 0, \quad \text{for all } i \in T_{+0}^+(\xi) \cup T_{+-}^+(\xi) \cup T_{00}^+(\xi) \cup T_{0-}^+(\xi),$$

$$\langle -\nabla \omega_i(\psi), \xi - \psi \rangle \leq 0, \lambda_i^\omega < 0, \quad \text{for all } i \in T_{+0}^-(\xi) \cup T_{0+}^-(\xi) \cup T_{00}^-(\xi),$$

Employing this together with (23) gives us the inequality

$$\left\langle \sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle$$

$$= -\left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\psi), \xi - \psi \right\rangle$$

$$\geq 0. \tag{26}$$

Assume by contradiction that

$$\vartheta(\xi) \preceq_{LU} \vartheta(\psi).$$

This is equivalent to

$$\begin{cases} \vartheta^L(\xi) < \vartheta^L(\psi) \\ \vartheta^U(\xi) \leq \vartheta^U(\psi) \end{cases}, \quad \text{or} \quad \begin{cases} \vartheta^L(\xi) \leq \vartheta^L(\psi) \\ \vartheta^U(\xi) < \vartheta^U(\psi) \end{cases}, \quad \text{or} \quad \begin{cases} \vartheta^L(\xi) < \vartheta^L(\psi) \\ \vartheta^U(\xi) < \vartheta^U(\psi) \end{cases}.$$

Since $\vartheta_i^L, \vartheta_i^U$ $(i \in T)$ are strictly pseudoconvex functions at ψ, we have

$$\langle \nabla \vartheta_i^L(\psi), \xi - \psi \rangle < 0, \text{ for all } i \in T,$$
$$\langle \nabla \vartheta_i^U(\psi), \xi - \psi \rangle < 0, \text{ for all } i \in T.$$

Taking into account $\alpha^L \in R_+^m, \alpha^U \in R_+^m$ and from $\sum_{i=1}^m \left(\alpha_i^L + \alpha_i^U \right) = 1$, we have

$$\left\langle \sum_{i=1}^m \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i=1}^m \alpha_i^U \nabla \vartheta_i^U(\psi), \xi - \psi \right\rangle < 0,$$

contradicting to (26). $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\square$

Example 3. Let $m = n = 1$, let $p = q = 0$ and let $r = 1$. Let us investigate the following $(MIVVC - 3)$:

$MIVVC-3 \qquad \mathbb{R}_+ - \min \ \vartheta(\xi) = (\vartheta_1(\xi), \vartheta_2(\xi))$
$$= \left([4\xi^2 - \xi, 4\xi^2 + \xi + 1], \ [\xi^2 - 2\xi, \xi^4 + 2\xi]\right)$$

subject to

$$\rho_1(\xi) = \xi \geq 0,$$
$$\omega_1(\xi)\rho_1(\xi) = (-1 - \xi)\xi \leq 0.$$

Then, $\mathbb{F}_{\mathbb{VC}3} = \{\xi \in R \mid \rho_1(\xi) \geq 0, \ \omega_1(\xi)\rho_1(\xi) \leq 0\}$. For any $\xi_0 \in \mathbb{F}_{\mathbb{VC}3}$, the corresponding Mond–Weir dual problem to MIVVC-3 is given by

$(MWD_M - 1) \ R_+^m - \max \ \vartheta(u)$
$$= \left([4u^2 - u, 4u^2 + u + 1], [u^2 - 2u, u^4 + 2u]\right)$$

subject to

$$\alpha_1^L(8u - 1) + \alpha_1^U(8u + 1) + \alpha_2^L(2u - 2) + \alpha_2^U(4u^3 + 2)$$
$$- \lambda_1^\rho(1) + \lambda_1^\omega(-1) = 0, -\lambda_1^\rho(u) \geq 0, \lambda_1^\omega(-1 - u) \geq 0,$$
$$\alpha_1^L + \alpha_1^U = 1, \alpha_2^L + \alpha_2^U = 1,$$

$$\lambda_1^\rho \begin{cases} \geq 0, \ if 1 \in T_+(\xi_0), \\ \in R, \ if 1 \in T_0(\xi_0), \end{cases} \quad \lambda_1^\omega \begin{cases} \leq 0, \ if 1 \in T_{0+}(\xi_0), \\ \geq 0, \ if 1 \in T_{+-}(\xi_0) \cup T_{0-}(\xi_0), \\ \in R, \ if 1 \in T_{+0}(\xi_0) \cup T_{00}(\xi_0), \end{cases}$$

$where \ (u, \alpha_1^L, \alpha_1^U, \alpha_2^L, \alpha_2^U, \lambda_1^\omega, \lambda_1^\rho) \in R \times R_+ \times R_+ \times R_+ \times R_+ \times R \times R.$

Therefore, we get the following feasible set of problem $(MWD_M(\xi_0) - 1)$:

$$(\mathbb{F}_{\mathbb{VC}M}(\xi_0) - 1) := \Bigg\{ (u, \alpha_1^L, \alpha_1^U, \alpha_2^L, \alpha_2^U, \lambda^\omega, \lambda^\rho) \in R^n \times R_+^m \times R_+^m \times R_+^m$$
$$\times R_+^m \times R^r \times R^r \mid -\lambda_1^\rho(u) \geq 0, \lambda_1^\omega(-1 - u) \geq 0,$$
$$\alpha_1^L + \alpha_1^U = 1, \alpha_2^L + \alpha_2^U = 1, \lambda_1^\rho \in R, \lambda_1^\omega \in R,$$
$$\alpha_1^L \nabla \vartheta_1^L(u) + \alpha_1^U \nabla \vartheta_1^U(u) + \alpha_2^L \nabla \vartheta_2^L(u)$$
$$+ \alpha_2^U \nabla \vartheta_2^U(u) - \lambda_1^\rho \nabla \rho_1(u) + \lambda_1^\omega \nabla \omega_1(u) = 0 \Bigg\}.$$

By taking $\xi_0 = 0 \in \mathbb{F}_{\mathbb{VC}3}$, we evidence from Examples 1 and 2 that all suppositions of Theorem 1 are fulfilled. Now, by choosing $\alpha_1^L = \alpha_1^U = \frac{1}{2}, \alpha_2^L = \alpha_2^U = \frac{1}{2}, \lambda_1^\omega = 0, \lambda_1^\rho = 0$,
we have

$$-\lambda_1^\rho(\xi_0) \geq 0, \qquad \lambda_1^\omega(-1 - \xi_0) \geq 0,$$
$$\frac{1}{2}(-1) + \frac{1}{2}(1) + \frac{1}{2}(-2) + \frac{1}{2}(2) - \lambda_1^\rho(1) + \lambda_1^\omega(-1) = 0.$$

Finally, by the strict pseudoconvexity of $\vartheta_i^L, \vartheta_i^U (i \in T)$ at ψ on $\mathbb{F}_{\mathbb{VC}M} \cup \Gamma_M$ and by simple calculations, we get $\vartheta(\xi) \not\preceq_{LU} \vartheta(\psi)$.

Theorem 8 (Strong duality)**.** Let $\xi_0 \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$ be a locally weakly efficient solution of MIVVC. If MIVVC-VACQ holds at ξ_0 and the set Δ_1 is closed, then there exists $(\bar{\alpha}^L, \bar{\alpha}^U, \ \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i=1}^m \left(\bar{\alpha}_i^L + \bar{\alpha}_i^U\right) = 1, \bar{\lambda}_{T_+(\xi_0)}^\rho = 0, \bar{\lambda}_{T_{00}(\xi_0) \cup T_{0-}(\xi_0)}^\rho \geq 0, \bar{\lambda}_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)}^\omega = 0$ and $\bar{\lambda}_{T_{+0}(\xi_0) \cup T_{00}(\xi_0)}^\omega \geq 0$ such that $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0)$. Furthermore, assume that $\tau_i(i \in T_\tau^+(\xi_0)), \sigma_i(i \in T_\sigma^+(\xi_0)), -\sigma_i(i \in T_\sigma^-(\xi_0)), \rho_i(i \in \hat{T}_0^-(\xi_0)), -\rho_i(i \in \hat{T}_+^+(\xi_0) \cup \hat{T}_0^+(\xi_0)), \omega_i(i \in T_{+0}^+(\xi_0) \cup T_{+-}^+(\xi_0) \cup T_{00}^+(\xi_0) \cup T_{0-}^+(\xi_0)), -\omega_i(i \in T_{+0}^-(\xi_0) \cup T_{0+}^-(\xi_0) \cup T_{00}^-(\xi_0))$ are quasiconvex functions at ξ_0. If $\vartheta_i^L, \vartheta_i^U(i \in T)$ are strictly pseudoconvex functions at ξ_0, then $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho)$ is an LU-efficient solution of $MWD_M(\xi_0)$.

Proof. By Theorem (1), there exists $(\bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ with $\sum_{i=1}^m \left(\alpha_i^L + \alpha_i^U\right) = 1, \bar{\lambda}_{T_+(\xi_0)}^\rho = 0, \bar{\lambda}_{T_{00}(\xi_0) \cup T_{0-}(\xi_0)}^\rho \geq 0, \bar{\lambda}_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)}^\omega = 0$ and $\bar{\lambda}_{T_{+0}(\xi_0) \cup T_{00}(\xi_0)}^\omega \geq 0$ such that

$$\sum_{i \in T} \alpha_i^L \nabla \vartheta_i^L(\psi) + \sum_{i \in T} \alpha_i^U \nabla \vartheta_i^U(\psi) + \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\psi) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\psi)$$

$$- \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\psi) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\psi) = 0.$$

Since $\bar{\lambda}^\tau \in R^p$, one has $\bar{\lambda}_i^\tau \tau_i(\xi_0) = 0$ for all $i \in T_\tau$. The fact that $\xi_0 \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$ guarantees that $\bar{\lambda}_i^\sigma \sigma_i(\xi_0) = 0$. Furthermore, we deduce from $\bar{\lambda}_{T_+(\xi_0)}^\rho = 0$ and $\rho_i(\xi_0) = 0$ for all $i \in T_0(\xi_0)$ that $-\bar{\lambda}_i^\rho \rho_i(\xi_0) = 0$ for all $i \in T_r$. In addition, we get from $\bar{\lambda}_{T_{+-}(\xi_0) \cup T_{0+}(\xi_0) \cup T_{0-}(\xi_0)}^\omega = 0$ and $\omega_i(\xi_0) = 0$ for all $i \in T_{+0}(\xi_0) \cup T_{00}(\xi_0)$, that $\bar{\lambda}_i^\omega \omega_i(\xi_0) = 0$ for all $i \in T_r$. Thus, $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0)$.

(i). Now, arguing by contradiction, let us suppose that $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho)$ is not a weakly LU-efficient solution of $MWD_M(\xi_0)$. By the definition, there exists $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0)$ such that

$$\vartheta(\xi_0) \prec_{LU} \vartheta(u),$$

which contradicts with Theorem 4(i).

(ii). Reasoning to the contrary, Let us assume that $(\xi_0, \bar{\alpha}^L, \bar{\alpha}^U, \bar{\lambda}^\tau, \bar{\lambda}^\sigma, \bar{\lambda}^\omega, \bar{\lambda}^\rho)$ is not an LU-efficient solution of $MWD_M(\xi_0)$. Then, there exists $(u, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in \mathbb{F}_{\mathbb{V}\mathbb{C}M}(\xi_0)$ such that

$$\vartheta(\xi_0) \preceq_{LU} \vartheta(u)$$

which contradicts with Theorem 4(ii), and thus, completes the proof. $\square$

Theorem 9 (Strict converse duality)**.** Let $\tilde{\xi} \in \mathbb{F}_{\mathbb{V}\mathbb{C}}$ be a locally weakly efficient solution of MIVVC such that MIVVC-VACQ holds at $\tilde{\xi}$ and the strong

duality between the MIVVC and the $(MWD_M)(\tilde{\xi})$ as in Theorem 8 holds. Also, let $(\tilde{\psi}, \tilde{\alpha}^L, \tilde{\alpha}^U, \tilde{\lambda}^\tau, \tilde{\lambda}^\sigma, \tilde{\lambda}^\omega, \tilde{\lambda}^\rho) \in \mathbb{F}_{\mathbb{VC}M}$ be an LU-efficient solution of $(MWD_M)(\tilde{\xi})$. Moreover, Suppose that $\vartheta_i^L, \vartheta_i^U (i \in T)$ are strictly pseudoconvex functions and that $\tau_i(i \in T_\tau^+(\tilde{\xi})), \sigma_i(i \in T_\sigma^+(\tilde{\xi})), -\sigma_i(i \in T_\sigma^-(\tilde{\xi})), \rho_i(i \in \hat{T}_0^-(\tilde{\xi})), -\rho_i(i \in \hat{T}_+^+(\tilde{\xi}) \cup \hat{T}_0^+(\tilde{\xi})), \omega_i(i \in T_{+0}^+(\tilde{\xi}) \cup T_{+-}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi})), -\omega_i(i \in T_{+0}^-(\tilde{\xi}) \cup T_{0+}^-(\tilde{\xi}) \cup T_{00}^-(\tilde{\xi}))$ are quasiconvex functions at $\tilde{\psi}$ on $\mathbb{F}_{\mathbb{VC}M} \cup \Gamma_M$, respectively.

Proof. Suppose, contrary to the result, that $\tilde{\xi} \neq \tilde{\psi}$. Then, by the strong duality theorem, there exist $(\alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho) \in R_+^m \times R_+^m \times R^p \times R^q \times R^r \times R^r$ such that $(\tilde{\psi}, \alpha^L, \alpha^U, \lambda^\tau, \lambda^\sigma, \lambda^\omega, \lambda^\rho)$ is an LU-efficient solution of $MWD_M(\tilde{\xi})$, and hence

$$\vartheta(\tilde{\xi}) = \vartheta(\tilde{\psi}). \tag{27}$$

By the strict pseudoconvexity of $\vartheta_i^L, \vartheta_i^U (i \in T)$ at $\tilde{\psi}$ on $\mathbb{F}_{\mathbb{VC}M} \cup \Gamma_M$, we have

$$\left\langle \sum_{i=1}^m \alpha_i^L \nabla \vartheta_i^L(\tilde{\psi}) + \sum_{i=1}^m \alpha_i^U \nabla \vartheta_i^U(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle < 0. \tag{28}$$

By the quasiconvexity of $\tau_i(i \in T_\tau^+(\tilde{\xi})), \sigma_i(i \in T_\sigma^+(\tilde{\xi})), -\sigma_i(i \in T_\sigma^-(\tilde{\xi})), \rho_i(i \in \hat{T}_0^-(\tilde{\xi})), -\rho_i(i \in \hat{T}_+^+(\tilde{\xi}) \cup \hat{T}_0^+(\tilde{\xi})), \omega_i(i \in T_{+0}^+(\tilde{\xi}) \cup T_{+-}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi})), -\omega_i(i \in T_{+0}^-(\tilde{\xi}) \cup T_{0+}^-(\tilde{\xi}) \cup T_{00}^-(\tilde{\xi}))$ at $\tilde{\psi}$ on $\mathbb{F}_{\mathbb{VC}} \cup \Gamma_{MWD}$ and by the definitions of index sets, we have

$$\left\langle \nabla \tau_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\tau > 0, \quad \text{for all } i \in T_\tau^+(\tilde{\xi}),$$

$$\left\langle \nabla \sigma_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\sigma > 0, \quad \text{for all } i \in T_\sigma^+(\tilde{\xi}),$$

$$\left\langle -\nabla \sigma_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\sigma < 0, \quad \text{for all } i \in T_\sigma^-(\tilde{\xi}),$$

$$\left\langle \nabla \rho_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\rho < 0, \quad \text{for all } i \in \hat{T}_0^-(\tilde{\xi}),$$

$$\left\langle -\nabla \rho_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\rho > 0, \quad \text{for all } i \in \hat{T}_+^+(\tilde{\xi}) \cup \hat{T}_0^+(\tilde{\xi}),$$

$$\left\langle \nabla \omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\omega > 0, \quad \text{for all } i \in T_{+0}^+(\tilde{\xi}) \cup T_{+-}^+(\tilde{\xi}) \cup T_{00}^+(\tilde{\xi}) \cup T_{0-}^+(\tilde{\xi}),$$

$$\left\langle -\nabla \omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0, \lambda_i^\omega < 0, \quad \text{for all } i \in T_{+0}^-(\tilde{\xi}) \cup T_{0+}^-(\tilde{\xi}) \cup T_{00}^-(\tilde{\xi}),$$

which implies that

$$\left\langle \sum_{i \in T_\tau} \lambda_i^\tau \nabla \tau_i(\tilde{\psi}) + \sum_{i \in T_\sigma} \lambda_i^\sigma \nabla \sigma_i(\tilde{\psi}) - \sum_{i \in T_r} \lambda_i^\rho \nabla \rho_i(\tilde{\psi}) + \sum_{i \in T_r} \lambda_i^\omega \nabla \omega_i(\tilde{\psi}), \tilde{\xi} - \tilde{\psi} \right\rangle \leq 0. \tag{29}$$

On adding the inequalities (28) and (29) and by using the duality constraint of $(MWD_M(\xi_0))$, we have

$$\vartheta(\tilde{\psi}) \prec_{LU} \vartheta(\tilde{\xi}).$$

which contradicts with (27).   □

6 Special cases

(*i*). If $\vartheta_1(\xi) = \vartheta_2(\xi) = \cdots = \vartheta_m(\xi)$ then the MIVVC problem reduces to the following (IVVC) problem of Ahmad et al. [2]:

$$
\begin{aligned}
\text{(P-1)} \quad &\min \quad \vartheta(\xi) = (\vartheta_1(\xi)) = [\vartheta_1^L(\xi), \vartheta_1^U(\xi)] \\
&\text{subject to} \\
&\tau_i(\xi) \le 0, \quad \text{for all } i = 1, 2, \ldots, p, \\
&\sigma_i(\xi) = 0, \quad \text{for all } i = 1, 2, \ldots, q, \\
&\rho_i(\xi) \ge 0, \quad \text{for all } i = 1, 2, \ldots, r, \\
&\omega_i(\xi)\rho_i(\xi) \le 0, \quad \text{for all } i = 1, 2, \ldots, r.
\end{aligned}
$$

(*ii*). If $\vartheta_1(\xi) = \vartheta_2(\xi) = \cdots = \vartheta_m(\xi)$ and $\vartheta_1^L(\xi) = \vartheta_1^U(\xi)$ then the MIVVC problem reduces to the following (MPVC) problem of Hoheisel and Kanzow [12] and the (MPVC) problem of Ahmad, Kummari, and Al-Homidan [3]:

$$
\begin{aligned}
\text{(P-2)} \quad &\min \quad \vartheta(\xi) \\
&\text{subject to} \\
&\tau_i(\xi) \le 0, \quad \text{for all } i = 1, 2, \ldots, p, \\
&\sigma_i(\xi) = 0, \quad \text{for all } i = 1, 2, \ldots, q, \\
&\rho_i(\xi) \ge 0, \quad \text{for all } i = 1, 2, \ldots, r, \\
&\omega_i(\xi)\rho_i(\xi) \le 0, \quad \text{for all } i = 1, 2, \ldots, r.
\end{aligned}
$$

(*iii*). If $\rho_i(\xi) = 0 = \omega_i(\xi)$, for all $i = 1, 2, \ldots, r$, then MIVVC problem reduces to the following IVP problem of Antczak and Michalak [5]:

$$
\begin{aligned}
\text{(P-3)} \quad &\min \quad \vartheta(\xi) = (\vartheta_1(\xi), \vartheta_2(\xi), \ldots, \vartheta_m(\xi)) \\
&\text{subject to} \\
&\tau_i(\xi) \le 0, \quad \text{for all } i = 1, 2, \ldots, p, \\
&\sigma_i(\xi) = 0, \quad \text{for all } i = 1, 2, \ldots, q.
\end{aligned}
$$

As a result of the above special cases, it is evident that the problem MIVVC presented in this article is more generalized.

7 Conclusion

In this paper, we have considered a multiobjective interval-valued programming problem involving vanishing constraints. Based on generalized convexity assumptions, the sufficiency of the Karush–Khun–Tucker necessary optimality conditions has been established. Furthermore, we have anticipated Wolfe and Mond–Weir dual problems for the considered multiobjective programming problem with interval-valued objective function and delved into several duality results under convexity assumptions. The results established in the paper were exemplified by an example.

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How to cite this article

Optimality Conditions and Saddle Point Criteria for Fractional Interval-Valued Optimization Problem via Convexificator

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Abstract. In this work, we use the notion of convexificators to discuss optimality conditions for a fractional interval-valued optimization problem. We illustrate the sufficient optimality conditions established in the paper by the example of a nonconvex fractional interval-valued optimization problem with the help of generalized invex functions. Further, we study saddle point criteria of a Lagrange function defined for a fractional interval-valued optimization problem.

1. Introduction

In the last two decades, a large number of research has been devoted for solving fractional programming problems. This follows from the fact that optimization problems with the objective function of ratio of two functions have a wide range

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of applications in engineering and economics, game theory, and many more (cf. [12, 18, 22]).

Interval-valued optimization problem is used to tackle interval uncertainity that appears in many real world mathematical problems. For example, it is applied to solve the fixed-charge transportation problem [15], chemical engineering problem [17] and municipal solid waste management [20], etc. Interval-valued programming problem was first studied by Ben-Israel and Robers [2]. Wu [21] formulated four kinds of interval-valued optimization problems and discussed optimality conditions. Further, they also established duality results to relate the primal and dual problems. Singh et al. [16] proposed a theoretical and practical solution method for a multiobjective interval-valued programming problem. In the recent past, many mathematicians have shown their interest to study different types of interval-valued programming problems [1, 3, 11, 14, 19].

The notion of convexificators introduced by Demyanov [6] and extended further by Jeyakumar and Luc [10]. Convexificators can be viewed as weaker versions of the notion of subdifferentials as they are in general closed sets unlike the well-known subdifferentials which are convex and compact sets. In literature, a lot of research has been carried out for convexificators regarding its theoretical properties (see, e.g. [5, 7, 8, 11, 13] and the references therein). Recently, making use of these notions, Karush-Kuhn-Tucker necessary optimality conditions for local weak efficient solutions were established by Hejazi and Nobakhtian [9] for a multiobjective fractional programming problem. Also, Hejazi and Nobakhtian [9] gave some constraint qualifications and subsequently they discussed relationship between these constraint qualifications.

In this paper, by using the idea of convexificators, we study optimality conditions for a fractional interval-valued optimization problem. Further, we establish equivalence between the saddle point and LU optimal solution of the fractional interval-valued optimization problem involving generalized invex functions.

2. Preliminaries

In this section, we give a number of basic definitions and lemmas which will be used in the paper. Let R^n be the n-dimensional Euclidean space and R^n_+ be its non-negative orthant. Throughout this paper, we shall be concerned with Banach spaces. Let X^* be topological dual of a given Banach space X with the canonical dual pairing $\langle ., .\rangle$. Let X and Y be Banach spaces and we denote by $L(X, Y)$ the set of continuous linear mappings between X and Y.

Let $f : X \to R \cup \{+\infty\}$, be an extended real-valued function. Then

$$f^-(x, d) = \lim_{t \to 0+} \inf \frac{f(x + td) - f(x)}{t},$$

$$f^+(x, d) = \lim_{t \to 0+} \sup \frac{f(x + td) - f(x)}{t}$$

denote, respectively, the lower and upper Dini directional derivatives of f at

$x \in X$ in the direction of d.

Now, we begin with the definition of convexificator given by Jeyakumar and Luc [10].

Definition 2.1. *A function $f : X \to R \cup \{+\infty\}$ is said to have a convexificator $\partial^* f(x)$ at x if $\partial^* f(x) \subset X^*$ is weak* closed and*

$$f^+(x,d) \geq \inf_{x^* \in \partial^* f(x)} \langle x^*, d \rangle \text{ and } f^-(x,d) \leq \sup_{x^* \in \partial^* f(x)} \langle x^*, d \rangle, \ \forall d \in X.$$

Along the lines of Gadhi [8], we now give the definitions of generalized invex functions by using the concept of convexificators. Assume that $f : X \to R$ admits a convexificator $\partial^* f(\bar{x}) \subset L(X, R)$ at $\bar{x} \in X$.

Definition 2.2. *A function $f : X \to R$ is said to be $(\eta, \partial^* f)$-invex at $\bar{x} \in X$ if there exists $\eta : X \times X \to X$ such that,*

$$f(x) - f(\bar{x}) \geq \langle \xi, \eta(x, \bar{x}) \rangle, \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X.$$

If strict inequality holds in above definition for $x \neq \bar{x}$, then f is said to be strict $(\eta, \partial^* f)$-invex at $\bar{x}$.

Definition 2.3. *A function $f : X \to R$ is said to be $(\eta, \partial^* f)$-pseudoinvex at $\bar{x} \in X$ if there exists $\eta : X \times X \to X$ such that,*

$$f(x) < f(\bar{x}) \Rightarrow \langle \xi, \eta(x, \bar{x}) \rangle < 0, \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X,$$

equivalently

$$\langle \xi, \eta(x, \bar{x}) \rangle \geq 0 \Rightarrow f(x) \geq f(\bar{x}), \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X.$$

Definition 2.4. *A function $f : X \to R$ is said to be strict $(\eta, \partial^* f)$-pseudoinvex at $\bar{x} \in X$ if there exists $\eta : X \times X \to X$ such that,*

$$f(x) \leq f(\bar{x}) \Rightarrow \langle \xi, \eta(x, \bar{x}) \rangle < 0, \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X,$$

equivalently

$$\langle \xi, \eta(x, \bar{x}) \rangle \geq 0 \Rightarrow f(x) > f(\bar{x}), \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X.$$

Definition 2.5. *A function $f : X \to R$ is said to be $(\eta, \partial^* f)$-quasiinvex at $\bar{x} \in X$ if there exists $\eta : X \times X \to X$ such that,*

$$f(x) \leq f(\bar{x}) \Rightarrow \langle \xi, \eta(x, \bar{x}) \leq 0, \text{ for all } \xi \in \partial^* f(\bar{x}) \text{ and } x \in X,$$

equivalently

$$\langle \xi, \eta(x, \bar{x}) \rangle > 0 \Rightarrow f(x) > f(\bar{x}), \ \textit{for all } \xi \in \partial^* f(\bar{x}) \ \textit{and } x \in X.$$

In order to proceed further, we need the following fundamental concepts of interval mathematics:

Let $\dfrac{\mathbb{A}}{\mathbb{B}} = \left[\dfrac{\alpha_1^L}{\gamma_1^L}, \dfrac{\alpha_1^U}{\gamma_1^U}\right]$ and $\dfrac{\mathbb{C}}{\mathbb{D}} = \left[\dfrac{\alpha_2^L}{\gamma_2^L}, \dfrac{\alpha_2^U}{\gamma_2^U}\right]$ be two fractional closed intervals with $\dfrac{\alpha_1^L}{\gamma_1^L} \leq \dfrac{\alpha_1^U}{\gamma_1^U}$ and $\dfrac{\alpha_2^L}{\gamma_2^L} \leq \dfrac{\alpha_2^U}{\gamma_2^U}$, $\gamma_1^L, \gamma_1^U, \gamma_2^L, \gamma_2^U \neq 0$.

(i) $\dfrac{\mathbb{A}}{\mathbb{B}} + \dfrac{\mathbb{C}}{\mathbb{D}} = \left[\dfrac{\alpha_1^L}{\gamma_1^L} + \dfrac{\alpha_2^L}{\gamma_2^L}, \dfrac{\alpha_1^U}{\gamma_1^U} + \dfrac{\alpha_2^U}{\gamma_2^U}\right],$

(ii) $\dfrac{-\mathbb{A}}{\mathbb{B}} = \left[\dfrac{-\alpha_1^U}{\gamma_1^U}, \dfrac{-\alpha_1^L}{\gamma_1^L}\right],$

(iii) $\dfrac{\mathbb{A}}{\mathbb{B}} - \dfrac{\mathbb{C}}{\mathbb{D}} = \dfrac{\mathbb{A}}{\mathbb{B}} + \left(\dfrac{-\mathbb{C}}{\mathbb{D}}\right) = \left[\dfrac{\alpha_1^L}{\gamma_1^L} - \dfrac{\alpha_2^U}{\gamma_2^U}, \dfrac{\alpha_1^U}{\gamma_1^U} - \dfrac{\alpha_2^L}{\gamma_2^L}\right],$

(iv) $\beta\left(\dfrac{\mathbb{A}}{\mathbb{B}}\right) = \begin{cases} \left[\dfrac{\alpha_1^L}{\gamma_1^L}, \dfrac{\alpha_1^U}{\gamma_1^U}\right], & \text{if } \beta \geq 0, \\[3mm] \left[\dfrac{\alpha_1^U}{\gamma_1^U}, \dfrac{\alpha_1^L}{\gamma_1^L}\right], & \text{if } \beta < 0. \end{cases}$

An order relation $\leq_{LU}$ between two intervals $\dfrac{\mathbb{A}}{\mathbb{B}}$ and $\dfrac{\mathbb{C}}{\mathbb{D}}$ are defined as

(i) $\dfrac{\mathbb{A}}{\mathbb{B}} \leq_{LU} \dfrac{\mathbb{C}}{\mathbb{D}}$ iff $\dfrac{\alpha_1^L}{\gamma_1^L} \leq \dfrac{\alpha_2^L}{\gamma_2^L}$ and $\dfrac{\alpha_1^U}{\gamma_1^U} \leq \dfrac{\alpha_2^U}{\gamma_2^U}$.

(ii) $\dfrac{\mathbb{A}}{\mathbb{B}} < \dfrac{\mathbb{C}}{\mathbb{D}}$ iff $\dfrac{\mathbb{A}}{\mathbb{B}} \leq \dfrac{\mathbb{C}}{\mathbb{D}}$ and $\dfrac{\mathbb{A}}{\mathbb{B}} \neq \dfrac{\mathbb{C}}{\mathbb{D}}$, equivalently

$$\begin{cases} \dfrac{\alpha_1^L}{\gamma_1^L} < \dfrac{\alpha_2^L}{\gamma_2^L} \\[2mm] \dfrac{\alpha_1^U}{\gamma_1^U} \leq \dfrac{\alpha_2^U}{\gamma_2^U} \end{cases}, \text{ or } \begin{cases} \dfrac{\alpha_1^L}{\gamma_1^L} \leq \dfrac{\alpha_2^L}{\gamma_2^L} \\[2mm] \dfrac{\alpha_1^U}{\gamma_1^U} < \dfrac{\alpha_2^U}{\gamma_2^U} \end{cases}, \text{ or } \begin{cases} \dfrac{\alpha_1^L}{\gamma_1^L} < \dfrac{\alpha_2^L}{\gamma_2^L} \\[2mm] \dfrac{\alpha_1^U}{\gamma_1^U} < \dfrac{\alpha_2^U}{\gamma_2^U}. \end{cases}$$

Consider the following non-differentiable fractional interval-valued optimization problem:

$$\min \left[\dfrac{f^L(x), f^U(x)}{g^L(x), g^U(x)}\right]$$

subject to

$h_i(x) \leq 0, i = 1, 2, ..., m,$

$x \in X,$

which further reduces to the problem

$$\min \left[\frac{f^L(x)}{g^U(x)}, \frac{f^U(x)}{g^L(x)} \right]$$

subject to

$$h_i(x) \leq 0, i = 1, 2, ..., m,$$

$$x \in X,$$

where $f^L(x)$, $f^U(x) \geq 0$, $g^L(x)$, $g^U(x) > 0$, and h_i, $i = 1, 2, \ldots, m$ are continuous functions on X. Set $f^L = p^L$, $g^U = q^L$, $f^U = p^U$, $g^L = q^U$. Then, the above problem reduces to

$$\text{(NFIVP)} \qquad \min \left[\frac{p^L}{q^L}(x), \frac{p^U}{q^U}(x) \right]$$

subject to

$$h_i(x) \leq 0, i = 1, 2, ..., m,$$

$$x \in X.$$

Let $\mathbb{F}$ be the feasible set for the problem (NFIVP).

Definition 2.6. [21] *A feasible point $\bar{x}$ is said to be a LU optimal solution for (NFIVP) if and only if there exists no feasible point x such that*

$$\left[\frac{p^L}{q^L}(x), \frac{p^U}{q^U}(x) \right] <_{LU} \left[\frac{p^L}{q^L}(\bar{x}), \frac{p^U}{q^U}(\bar{x}) \right].$$

3. Optimality Conditions

For the given feasible solution $\bar{x}$, consider two fractional problems as given below:

(FP1) $\quad \min \phi^L(x) = \dfrac{p^L}{q^L}(x)$ $\qquad$ (FP2) $\quad \min \phi^U(x) = \dfrac{p^U}{q^U}(x)$

subject to $\qquad\qquad\qquad\qquad\qquad\qquad$ subject to

$h_i(x) \leq 0, \ i = 1, 2, \ldots, m,$ $\qquad\qquad$ $h_i(x) \leq 0, \ i = 1, 2, \ldots, m,$

$\dfrac{p^U}{q^U}(x) \leq \dfrac{p^U}{q^U}(\bar{x}),$ $\qquad\qquad\qquad$ $\dfrac{p^L}{q^L}(x) \leq \dfrac{p^L}{q^L}(\bar{x}),$

$x \in X.$ $\qquad\qquad\qquad\qquad\qquad\qquad$ $x \in X.$

The following result gives the relationship between (NFIVP) and (FP1) and (FP2).

Lemma 3.1. [4] *If $\bar{x}$ is a LU optimal solution for the problem (NFIVP) if and only if $\bar{x}$ is an optimal solution for the problems (FP1) and (FP2).*

Lemma 3.2. [4] $\bar{x}$ *is a LU optimum of the problem* (NFIVP) *if and only if* $\bar{x}$ *minimizes* $\frac{p^L}{q^L}(x)$ *on the following constraint set*

$$N = \left\{ x \in X | \frac{p^U}{q^U}(x) \leq \frac{p^U}{q^U}(\bar{x}), h_i(x) \leq 0, i = 1, 2, \ldots, m \right\}.$$

Considered the following single-objective fractional problem:

$$\text{(D)} \qquad \min \phi(x) = \frac{p_1}{q_1}(x)$$

$$\text{subject to}$$

$$\ell_i(x) \leq 0, i = 1, 2, \ldots, m,$$

$$x \in X,$$

where p_1, q_1 and ℓ_i, $i = 1, 2, \ldots, m$ are continuous functions on X such that $p_1(x) \geq 0$ and $q_1(x) > 0$, for all $x \in X$.

On the lines of Theorem 6 of Gadhi [8], we state the following theorem for the problem (D):

Theorem 3.3. *Suppose that* $\bar{x}$ *is an optimal solution of the problem (D) and a suitable constraint qualification is satisfied at* $\bar{x}$. *Assume that* p_1, q_1 *and* ℓ_i, $i = 1, 2, \ldots, m$ *are continuous and admit bounded convexificators* $\partial^* p_1(\bar{x})$, $\partial^* q_1(\bar{x})$ *and* $\partial^* \ell_i(\bar{x})$, $i = 1, 2, \ldots, m$ *at* $\bar{x}$ *respectively and that* $\partial^* p_1(\bar{x})$, $\partial^* q_1(\bar{x})$ *and* $\partial^* \ell_i(\bar{x})$, $i = 1, 2, \ldots, m$ *are upper semicontinuous at* $\bar{x}$, *then there exist* $\lambda > 0$, *and* $\mu \in R_+^m$ *such that*

$$0 \in \lambda \left(\partial^* p_1(\bar{x}) - \phi(\bar{x}) \partial^* q_1(\bar{x}) \right) + \sum_{i=1}^{m} \mu_i \partial^* \ell_i(\bar{x}), \tag{1}$$

$$\mu_i \ell_i(\bar{x}) = 0, j = 1, 2, \ldots, m, \tag{2}$$

$$\mu_i \geq 0 \text{ and } \ell_i(\bar{x}) \leq 0, \ i = 1, 2, \ldots, m. \tag{3}$$

Theorem 3.4. (Karush-Kuhn-Tucker Necessary Optimality Conditions) *Suppose that* $\bar{x}$ *is a LU optimal solution of the problem* (NFIVP) *and a suitable constraint qualification is satisfied at* $\bar{x}$. *Assume that* p^L, q^L, p^U, q^U *and* h_i, $i = 1, 2, \ldots, m$ *are continuous and admit bounded convexificators* $\partial^* p^L(\bar{x})$, $\partial^* q^L(\bar{x})$, $\partial^* p^U(\bar{x})$, $\partial^* q^U(\bar{x})$ *and* $\partial^* h_i(\bar{x})$, $i = 1, 2, \ldots, m$ *at* $\bar{x}$ *respectively and that* $\partial^* p^L(\bar{x})$, $\partial^* q^L(\bar{x})$, $\partial^* p^L(\bar{x})$, $\partial^* q^L(\bar{x})$, *and* $\partial^* h_i(\bar{x})$, $i = 1, 2, \ldots, m$ *are upper semicontinuous at* $\bar{x}$, *then there exist* $\lambda^L > 0$, $\lambda^U > 0$ *and* $\mu \in R_+^m$ *such that*

$$0 \in \lambda^L \left(\partial^* p^L(\bar{x}) - \phi^L(\bar{x}) \partial^* q^L(\bar{x}) \right)$$

$$+ \lambda^U \left(\partial^* p^U(\bar{x}) - \phi^U(\bar{x}) \partial^* q^U(\bar{x}) \right) + \sum_{i=1}^{m} \mu_i \partial^* h_i(\bar{x}), \tag{4}$$

$$\mu_i h_i(\bar{x}) = 0, j = 1, 2, \ldots, m, \tag{5}$$

$$\mu_i \geq 0 \text{ and } h_i(\bar{x}) \leq 0, \ i = 1, 2, \ldots, m. \tag{6}$$

Proof. By assumption, $\bar{x}$ is a LU optimal solution for the problem (NFIVP), and a suitable constraint qualification is satisfied at $\bar{x}$. Since $\bar{x}$ is an LU optimal solution, by Lemma 3.1, $\bar{x}$ is also a optimal solution for the problems (FP1) and (FP2). Hence, by Lemma 3.2, at $\bar{x}$ the minimum value of $\dfrac{p^L}{q^L}(x)$ is obtained on the constraint set

$$N_L = \left\{ x \in X | \frac{p^U}{q^U}(x) \leq \frac{p^U}{q^U}(\bar{x}), h_i(x) \leq 0, i = 1, 2, ..., m \right\},$$

and the minimum value of $\dfrac{p^U}{q^U}(x)$ is obtained at $\bar{x}$ on the constraint set

$$N_U = \left\{ x \in X | \frac{p^L}{q^L}(x) \leq \frac{p^L}{q^L}(\bar{x}), h_i(x) \leq 0, i = 1, 2, ..., m \right\}.$$

By Theorem 3.3, it follows that there exist $\lambda^{LL} > 0, \lambda^{LU} > 0, \mu^L \in R_+^m$ and $\lambda^{UL} > 0, \lambda^{UU} > 0, \mu^U \in R_+^m$ such that

$$0 \in \lambda^{LL} \left(\partial^* p^L(\bar{x}) - \phi^L(\bar{x}) \partial^* q^L(\bar{x}) \right)$$

$$+\lambda^{LU} \left(\partial^* p^U(\bar{x}) - \phi^U(\bar{x}) \partial^* q^U(\bar{x}) \right) + \sum_{i=1}^{m} \mu_i^L \partial^* h_i(\bar{x}), \tag{7}$$

$$\mu_i^L h_i(\bar{x}) = 0, j = 1, 2, ..., m, \tag{8}$$

$$\mu_i^L \geq 0 \text{ and } h_i(\bar{x}) \leq 0, \ i = 1, 2, ..., m. \tag{9}$$

and

$$0 \in \lambda^{UL} \left(\partial^* p^L(\bar{x}) - \phi^L(\bar{x}) \partial^* q^L(\bar{x}) \right)$$

$$+\lambda^{UU} \left(\partial^* p^U(\bar{x}) - \phi^U(\bar{x}) \partial^* q^U(\bar{x}) \right) + \sum_{i=1}^{m} \mu_i^U \partial^* h_i(\bar{x}), \tag{10}$$

$$\mu_i^U h_i(\bar{x}) = 0, j = 1, 2, ..., m, \tag{11}$$

$$\mu_i^U \geq 0 \text{ and } h_i(\bar{x}) \leq 0, \ i = 1, 2, ..., m. \tag{12}$$

From (7) to (12), we have

$$0 \in [\lambda^{LL} + \lambda^{UL}] \left(\partial^* p^L(\bar{x}) - \phi^L(\bar{x}) \partial^* q^L(\bar{x}) \right)$$

$$+[\lambda^{LU} + \lambda^{UU}] \left(\partial^* p^U(\bar{x}) - \phi^U(\bar{x}) \partial^* q^U(\bar{x}) \right) + \sum_{i=1}^{m} [\mu_i^L + \mu_i^U] \partial^* h_i(\bar{x}), \tag{13}$$

$$[\mu_i^L + \mu_i^U] h_i(\bar{x}) = 0, j = 1, 2, ..., m, \tag{14}$$

$$[\mu_i^L + \mu_i^U] \geq 0 \text{ and } h_i(\bar{x}) \leq 0, \ i = 1, 2, ..., m. \tag{15}$$

Let us denote $\lambda^{LL} + \lambda^{UL} = \lambda^L$, $\lambda^{LU} + \lambda^{UU} = \lambda^U$ and $\mu^L + \mu^U = \mu$. Thus, from

(13)-(15), it yields

$$0 \in \lambda^L \left(\partial^* p^L(\bar{x}) - \phi^L(\bar{x}) \partial^* q^L(\bar{x}) \right)$$

$$+ \lambda^U \left(\partial^* p^U(\bar{x}) - \phi^U(\bar{x}) \partial^* q^U(\bar{x}) \right) + \sum_{i=1}^{m} \mu_i \partial^* h_i(\bar{x}),$$

$$\mu_i h_i(\bar{x}) = 0, j = 1, 2, ..., m,$$

$$\mu_i \geq 0 \text{ and } h_i(\bar{x}) \leq 0, \ i = 1, 2, ..., m.$$

This completes the proof.   ∎

Theorem 3.5. (Sufficient Optimality Conditions) *Suppose that $\bar{x}$ is a feasible solution of* (NFIVP) *and there exist $\lambda^L > 0, \lambda^U > 0, \mu \in R_+^m$ such that* (4)–(6) *are satisfied at $\bar{x}$. Also, assume that*

(i) $p^L(.) - \phi^L(\bar{x})q^L(.)$ *and* $p^U(.) - \phi^U(\bar{x})q^U(.)$ *are respectively $(\eta, \partial^* p^L - \phi^L(\bar{x})\partial^* q^L)$-invex and $(\eta, \partial^* p^U - \phi^U(\bar{x})\partial^* q^U)$-invex at $\bar{x}$,*

(ii) $\mu_i h_i$, *for* $i = 1, 2, ..., m$, *is* $(\eta, \partial^* h_i(.))$-*invex at $\bar{x}$.*

   Then $\bar{x}$ is a LU optimal solution for (NFIVP).

Proof. By assumption, (4)-(6) are satisfied at $\bar{x}$ with Lagrange multipliers $\lambda^L > 0, \lambda^U > 0, \mu \in R_+^m$. As it follows from (4), there exist $\xi^L \in \partial^* p^L(\bar{x})$, $\nu^L \in \partial^* q^L(\bar{x})$, $\xi^U \in \partial^* p^U(\bar{x})$, $\nu^U \in \partial^* q^U(\bar{x})$, and $\zeta_i \in \partial^* h_i(\bar{x})$, $i = 1, 2, ..., m$, such that

$$\lambda^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right] + \lambda^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right] + \sum_{i=1}^{m} \mu_i \zeta_i = 0. \qquad (16)$$

Suppose contrary to the result, that $\bar{x}$ is not a LU optimal solution for (NFIVP). Hence, by Definition 2.6, there exists a feasible solution x such that

$$\left[\frac{p^L}{q^L}(x), \frac{p^U}{q^U}(x) \right] <_{LU} \left[\frac{p^L}{q^L}(\bar{x}), \frac{p^U}{q^U}(\bar{x}) \right]$$

that is $\begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) \leq \dfrac{p^U}{q^U}(\bar{x}) \end{cases}$, or $\begin{cases} \dfrac{p^L}{q^L}(x) \leq \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}$, or $\begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}$.

   This implies

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) \leq p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) \leq p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$
$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}).$$

From hypothesis (i), $p^L(.) - \phi^L(\bar{x})q^L(.)$ and $p^U(.) - \phi^U(\bar{x})q^U(.)$ are respectively $(\eta, \partial^* p^L - \phi^L(\bar{x})\partial^* q^L)$-invex and $(\eta, \partial^* p^U - \phi^U(\bar{x})\partial^* q^U)$-invex at $\bar{x}$ and therefore, there exists $\eta : X \times X \to X$ such that

$$\left\langle \left[\xi^L - \phi^L(\bar{x})\nu^L \right], \eta(x, \bar{x}) \right\rangle \le 0, \text{ for all } \xi^L \in \partial^* p^L(\bar{x}), \text{ and } \nu^L \in \partial^* q^L(\bar{x}),$$

$$\left\langle \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle < 0, \text{ for all } \xi^U \in \partial^* p^U(\bar{x}), \text{ and } \nu^U \in \partial^* q^U(\bar{x}),$$

or

$$\left\langle \left[\xi^L - \phi^L(\bar{x})\nu^L \right], \eta(x, \bar{x}) \right\rangle < 0, \text{ for all } \xi^L \in \partial^* p^L(\bar{x}), \text{ and } \nu^L \in \partial^* q^L(\bar{x}),$$

$$\left\langle \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle \le 0, \text{ for all } \xi^U \in \partial^* p^U(\bar{x}), \text{ and } \nu^U \in \partial^* q^U(\bar{x}),$$

or

$$\left\langle \left[\xi^L - \phi^L(\bar{x})\nu^L \right], \eta(x, \bar{x}) \right\rangle < 0, \text{ for all } \xi^L \in \partial^* p^L(\bar{x}), \text{ and } \nu^L \in \partial^* q^L(\bar{x}),$$

$$\left\langle \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle < 0, \text{ for all } \xi^U \in \partial^* p^U(\bar{x}), \text{ and } \nu^U \in \partial^* q^U(\bar{x}).$$

From the fact $\lambda^L > 0$, $\lambda^U > 0$ and by above inequalities, we have

$$\left\langle \lambda^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right] + \lambda^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle < 0. \tag{17}$$

On the other hand, by using the feasibility of x, $\mu_i \ge 0$, $i = 1, 2, ..., m$ and (5), we obtain

$$\mu_i h_i(x) \le \mu_i h_i(\bar{x}), i = 1, 2, ..., m,$$

which by hypothesis (ii), we get

$$\langle \mu_i \zeta_i, \eta(x, \bar{x}) \rangle \le 0, \text{ for all } \zeta_i \in \partial^* h_i(\bar{x}), \ i = 1, 2, ..., m. \tag{18}$$

On adding (17) and (18), we have

$$\left\langle \lambda^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right] + \lambda^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right] + \sum_{i=1}^m \mu_i \zeta_i, \eta(x, \bar{x}) \right\rangle < 0,$$

which contradicts (16). Hence, $\bar{x}$ is a LU optimal solution for (NFIVP). ∎

In order to illustrate the sufficient optimality conditions established in the Theorem 3.5, we consider the following example:

Example 3.6.

$$(\text{IVP1}) \qquad \min \left[\frac{f_1^L(x), f_1^U(x)}{g_1^L(x), g_1^U(x)} \right]$$

$$= \min \left[\frac{2x^2, x^2+1}{-x+4, -x^2+6} \right]$$

subject to

$$h_1(x) = -x + 2 \leq 0, x \in X = R.$$

Now, we rewrite the considered optimization problem in the following manner

$$\min \left[\frac{2x^2}{-x^2+6}, \frac{x^2+1}{-x+4} \right]$$

subject to

$$h_1(x) = -x + 2 \leq 0, x \in X = R.$$

where $\frac{p_1^L}{q_1^L}(x) = \frac{2x^2}{-x^2+6}$, $\frac{p_1^U}{q_1^U}(x) = \frac{x^2+1}{-x+4}$. The feasible set is $\mathbb{F}_1 = \{x : -x + 2 \leq 0, x \in S\}$. By simple calculations, for the feasible point $\bar{x} = 2$, we see that $\partial^* p^L(\bar{x}) = \{-8, 8\}$, $\partial^* q^L(\bar{x}) = \{-4, 4\}$, $\partial^* p^U(\bar{x}) = \{-4, 4\}$, $\partial^* q^U(\bar{x}) = \{-1, 1\}$ and $\partial^* h_1(\bar{x}) = \{-1, 1\}$. Also, we see that for the feasible point $\bar{x} = 2$, there exist $\lambda^L > 0, \lambda^U > 0, \mu \in R_+^m$ such that (4)-(6) are satisfied at $\bar{x}$ and it is easy to see that

(i) $p_1^L(.) - \phi_1^L(\bar{x})q_1^L(.)$ and $p_1^U(.) - \phi_1^U(\bar{x})q_1^U(.)$ are respectively $(\eta, \partial^* p_1^L - \phi_1^L(\bar{x})\partial^* q_1^L)$-invex and $(\eta, \partial^* p_1^U - \phi_1^U(\bar{x})\partial^* q_1^U)$-invex at $\bar{x}$,

(ii) μh_1 is $(\eta, \partial^* h_1(.))$-invex at $\bar{x}$.

Therefore, by Theorem 3.5, $\bar{x} = 2$ is a LU optimal solution for (IVP1).

Theorem 3.7. (Sufficient Optimality Conditions) *Suppose that $\bar{x}$ is a feasible solution of* (NFIVP) *and there exist* $\lambda^L > 0, \lambda^U > 0, \mu \in R_+^m$ *such that* (4)–(6) *are satisfied at* $\bar{x}$. *Also, assume that*

(i) $\lambda^L[p^L(.) - \phi^L(\bar{x})q^L(.)] + \lambda^U[p^U(.) - \phi^U(\bar{x})q^U(.)]$ *is* $(\eta, \lambda^L[\partial^* p^L - \phi^L(\bar{x})\partial^* q^L] + \lambda^U[\partial^* p^U - \phi^U(\bar{x})\partial^* q^U])$-*pseudoinvex at* $\bar{x}$,

(ii) $\mu_i h_i$, *for* $i = 1, 2, ..., m$, *is* $(\eta, \partial^* h_i(.))$-*quasiinvex at* $\bar{x}$.

Then $\bar{x}$ *is a LU optimal solution for* (NFIVP).

Proof. By assumption, (4)-(6) are satisfied at $\bar{x}$ with Lagrange multipliers $\lambda^L > 0, \lambda^U > 0, \mu \in R_+^m$. As it follows from (4), there exist $\xi^L \in \partial^* p^L(\bar{x})$, $\nu^L \in \partial^* q^L(\bar{x})$, $\xi^U \in \partial^* p^U(\bar{x})$, $\nu^U \in \partial^* q^U(\bar{x})$, and $\zeta_i \in \partial^* h_i(\bar{x})$, $i = 1, 2, ..., m$, such that

$$\lambda^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right] + \lambda^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right] + \sum_{i=1}^m \mu_i \zeta_i = 0. \qquad (19)$$

Suppose contrary to the result, that $\bar{x}$ is not a LU optimal solution for (NFIVP). Hence, by Definition 2.6, there exist a feasible solution x such that

$$\left[\frac{p^L}{q^L}(x), \frac{p^U}{q^U}(x)\right] <_{LU} \left[\frac{p^L}{q^L}(\bar{x}), \frac{p^U}{q^U}(\bar{x})\right]$$

that is

$$\begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) \le \dfrac{p^U}{q^U}(\bar{x}) \end{cases}, \text{ or } \begin{cases} \dfrac{p^L}{q^L}(x) \le \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}, \text{ or } \begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}.$$

This implies

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) \le p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) \le p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}).$$

From the fact $\lambda^L > 0$, $\lambda^U > 0$ and by above inequalities, we have

$$\lambda^L[p^L(x) - \phi^L(\bar{x})q^L(x)] + \lambda^U[p^U(x) - \phi^U(\bar{x})q^U(x)]$$
$$< \lambda^L[p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x})] + \lambda^U[p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x})].$$

From hypothesis (i), $\lambda^L[p^L(.) - \phi^L(\bar{x})q^L(.)] + \lambda^U[p^U(.) - \phi^U(\bar{x})q^U(.)]$ is $(\eta, \lambda^L[\partial^* p^L - \phi^L(\bar{x})\partial^* q^L] + \lambda^U[\partial^* p^U - \phi^U(\bar{x})\partial^* q^U])$-pseudoinvex at $\bar{x}$ and therefore, there exists $\eta : X \times X \to X$ such that

$$\left\langle \lambda^L\left[\xi^L - \phi^L(\bar{x})\nu^L\right] + \lambda^U\left[\xi^U - \phi^U(\bar{x})\nu^U\right], \eta(x, \bar{x})\right\rangle < 0, \qquad (20)$$

for all $\xi^L \in \partial^* p^L(\bar{x})$, $\nu^L \in \partial^* q^L(\bar{x})$, $\xi^U \in \partial^* p^U(\bar{x})$, and $\nu^U \in \partial^* q^U(\bar{x})$.

On the other hand, by using the feasibility of x, $\mu_i \ge 0$, $i = 1, 2, ..., m$ and (5), we obtain

$$\mu_i h_i(x) \le \mu_i h_i(\bar{x}), i = 1, 2, ..., m,$$

which by hypothesis (ii), we get

$$\langle \mu_i \zeta_i, \eta(x, \bar{x})\rangle \le 0, \text{ for all } \zeta_i \in \partial^* h_i(\bar{x}), \ i = 1, 2, ..., m. \qquad (21)$$

On adding (20) and (21), we have

$$\left\langle \lambda^L \left[\xi^L - \phi^L(\bar{x})\nu^L\right] + \lambda^U \left[\xi^U - \phi^U(\bar{x})\nu^U\right] + \sum_{i=1}^{m} \mu_i \zeta_i, \eta(x, \bar{x}) \right\rangle < 0,$$

which contradicts (19). Hence, $\bar{x}$ is a LU optimal solution for (NFIVP). ∎

4. Lagrangian Type Function and Saddle-point Analysis

In this section, for the feasible point $\bar{x} \in \mathbb{F}$, we define the Lagrangian type function for the primal problem (NFIVP) as follows:

$$L(x, \lambda^L, \lambda^U, \mu) = \lambda^L \left(p^L(x) - \phi^L(\bar{x})q^L(x)\right) + \lambda^U \left(p^U(x) - \phi^U(\bar{x})q^U(x)\right)$$

$$+ \sum_{i=1}^{m} \mu_i h_i(x)$$

where $x \in X$, $\lambda^L \geq 0$, $\lambda^U \geq 0$ and $\mu \in R_+^m$. Now, we define a saddle-point of $L(x, \lambda^L, \lambda^U, \mu)$ and subsequently we discuss its relation to the problem (NFIVP).

Definition 4.1. *A point* $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}) \in X \times R_+ \times R_+ \times R_+^m$ *is said to be a saddle point for* $L(x, \lambda^L, \lambda^U, \mu)$, *if*

  (i) $L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \mu) \leq L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$, *for all* $\mu \in R_+^m$,
  (ii) $L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}) \leq L(x, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$, *for all* $x \in X$.

Theorem 4.2. *Let* $\bar{\lambda}^L > 0$, $\bar{\lambda}^U > 0$ *and* $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$ *be a saddle point for* $L(x, \lambda^L, \lambda^U, \mu)$. *Then* $\bar{x}$ *is a LU optimal solution to* (NFIVP).

Proof. Suppose contrary to the result, that $\bar{x}$ is not a LU optimal solution for (NFIVP). Hence, by Definition 2.6, there exists a feasible solution x such that

$$\left[\frac{p^L}{q^L}(x), \frac{p^U}{q^U}(x)\right] <_{LU} \left[\frac{p^L}{q^L}(\bar{x}), \frac{p^U}{q^U}(\bar{x})\right]$$

that is

$$\begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) \leq \dfrac{p^U}{q^U}(\bar{x}) \end{cases}, \text{ or } \begin{cases} \dfrac{p^L}{q^L}(x) \leq \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}, \text{ or } \begin{cases} \dfrac{p^L}{q^L}(x) < \dfrac{p^L}{q^L}(\bar{x}) \\ \dfrac{p^U}{q^U}(x) < \dfrac{p^U}{q^U}(\bar{x}) \end{cases}$$

This implies

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$

$$p^U(x) - \phi^U(\bar{x})q^U(x) \leq p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) \le p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$
$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}),$$

or

$$p^L(x) - \phi^L(\bar{x})q^L(x) < p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}),$$
$$p^U(x) - \phi^U(\bar{x})q^U(x) < p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}).$$

By above inequalities and from $\lambda^L > 0$, $\lambda^U > 0$, we have

$$\bar{\lambda}^L[p^L(x) - \phi^L(\bar{x})q^L(x)] + \bar{\lambda}^U[p^U(x) - \phi^U(\bar{x})q^U(x)]$$
$$< \bar{\lambda}^L[p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x})] + \bar{\lambda}^U[p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x})]. \tag{22}$$

Since $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$ is a saddle point for $L(x, \lambda^L, \lambda^U, \mu)$, by Definition 4.1 (i), we get

$$L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \mu) \le L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}),$$

that is,

$$\sum_{i=1}^{m} \mu_i h_i(\bar{x}) \le \sum_{i=1}^{m} \bar{\mu}_i h_i(\bar{x}). \tag{23}$$

Taking $(\mu_1, \mu_2, ...\mu_{i-1}, \mu_i, \mu_{i+1}, ..., \mu_m) = (\bar{\mu}_1, \bar{\mu}_2, ...\bar{\mu}_{i-1}, \bar{\mu}_i + 1, \bar{\mu}_{i+1}, ..., \bar{\mu}_m)$ in the above inequality (23), we obtain

$$h_i(\bar{x}) \le 0, i = 1, 2, ..., m,$$

which shows that $\bar{x}$ is a feasible solution to (NFIVP).

Using $\bar{\mu} \in R_+^m$, above inequality implies

$$\bar{\mu}_i h_i(\bar{x}) \le 0, i = 1, 2, ..., m. \tag{24}$$

Again taking $\mu_i = 0$, $i = 1, 2, ..., m$, in the inequality (23), we get

$$\bar{\mu}_i h_i(\bar{x}) \ge 0, i = 1, 2, ..., m. \tag{25}$$

From the inequalities (24) and (25), we conclude that

$$\bar{\mu}_i h_i(\bar{x}) = 0, i = 1, 2, ..., m. \tag{26}$$

On other hand, since $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$ is a saddle point for $L(x, \lambda^L, \lambda^U, \mu)$, by Definition 4.1 (ii), we get

$$L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}) \le L(x, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}),$$

that is

$$\bar{\lambda}^L\left(p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x})\right) + \bar{\lambda}^U\left(p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x})\right) + \sum_{i=1}^{m}\bar{\mu}_i h_i(\bar{x})$$

$$\le \bar{\lambda}^L\left(p^L(x) - \phi^L(\bar{x})q^L(x)\right) + \bar{\lambda}^U\left(p^U(x) - \phi^U(\bar{x})q^U(x)\right) + \sum_{i=1}^{m}\bar{\mu}_i h_i(x)$$

Using the feasibilty of x of the problem (NFIVP) together with $\bar{\mu} \in R_+^m$ and (26), above inequality gives

$$\bar{\lambda}^L \left(p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x}) \right) + \bar{\lambda}^U \left(p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x}) \right)$$
$$\leq \bar{\lambda}^L \left(p^L(x) - \phi^L(\bar{x})q^L(x) \right) + \bar{\lambda}^U \left(p^U(x) - \phi^U(\bar{x})q^U(x) \right).$$

This contradicts (22). Hence the proof. ∎

Theorem 4.3. *Let $\bar{x}$ be a LU optimal solution to* (NFIVP) *and assume that there exist $\bar{\lambda}^L > 0, \bar{\lambda}^U > 0, \bar{\mu} \in R_+^m$ such that* (4)–(6) *are satisfied at $\bar{x}$. Also, assume that*

(i) $p^L(.) - \phi^L(\bar{x})q^L(.)$ *and* $p^U(.) - \phi^U(\bar{x})q^U(.)$ *are respectively* $(\eta, \partial^* p^L - \phi^L(\bar{x})\partial^* q^L)$-invex *and* $(\eta, \partial^* p^U - \phi^U(\bar{x})\partial^* q^U)$-invex *at $\bar{x}$.*

(ii) $\mu_i h_i$, *for $i = 1, 2, ..., m$, is* $(\eta, \partial^* h_i(.))$-invex *at $\bar{x}$.*
   Then $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$ is a saddle point for $L(x, \lambda^L, \lambda^U, \mu)$.

Proof. By assumption, (4)–(6) are satisfied at $\bar{x}$ with Lagrange multipliers $\bar{\lambda}^L > 0, \bar{\lambda}^U > 0, \bar{\mu} \in R_+^m$. As it follows from (4), there exist $\xi^L \in \partial^* p^L(\bar{x})$, $\nu^L \in \partial^* q^L(\bar{x})$, $\xi^U \in \partial^* p^U(\bar{x})$, $\nu^U \in \partial^* q^U(\bar{x})$, and $\zeta_i \in \partial^* h_i(\bar{x})$, $i = 1, 2, ..., m$, such that

$$\bar{\lambda}^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right] + \bar{\lambda}^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right] + \sum_{i=1}^m \bar{\mu}_i \zeta_i = 0. \tag{27}$$

From the hypothesis (i), $p^L(.) - \phi^L(\bar{x})q^L(.)$ and $p^U(.) - \phi^U(\bar{x})q^U(.)$ are respectively $(\eta, \partial^* p^L - \phi^L(\bar{x})\partial^* q^L)$-invex and $(\eta, \partial^* p^U - \phi^U(\bar{x})\partial^* q^U)$-invex at $\bar{x}$, therefore, there exists $\eta : X \times X \to X$ such that

$$[p^L(x) - \phi^L(\bar{x})q^L(x)] - [p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x})]$$
$$\geq \left\langle \left[\xi^L - \phi^L(\bar{x})\nu^L \right], \eta(x, \bar{x}) \right\rangle, \text{ for all } \xi^L \in \partial^* p^L(\bar{x}), \text{ and } \nu^L \in \partial^* q^L(\bar{x}),$$

and

$$[p^U(x) - \phi^U(\bar{x})q^U(x)] - [p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x})]$$
$$\geq \left\langle \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle, \text{ for all } \xi^U \in \partial^* p^U(\bar{x}), \text{ and } \nu^U \in \partial^* q^U(\bar{x}).$$

From the fact $\bar{\lambda}^L > 0, \bar{\lambda}^U > 0$ and by above inequalities, we have

$$\bar{\lambda}^L[p^L(x) - \phi^L(\bar{x})q^L(x)] - \bar{\lambda}^L[p^L(\bar{x}) - \phi^L(\bar{x})q^L(\bar{x})] \tag{28}$$
$$\geq \left\langle \bar{\lambda}^L \left[\xi^L - \phi^L(\bar{x})\nu^L \right], \eta(x, \bar{x}) \right\rangle, \text{ for all } \xi^L \in \partial^* p^L(\bar{x}), \text{ and } \nu^L \in \partial^* q^L(\bar{x}),$$

and

$$\bar{\lambda}^U[p^U(x) - \phi^U(\bar{x})q^U(x)] - \bar{\lambda}^U[p^U(\bar{x}) - \phi^U(\bar{x})q^U(\bar{x})] \tag{29}$$
$$\geq \left\langle \bar{\lambda}^U \left[\xi^U - \phi^U(\bar{x})\nu^U \right], \eta(x, \bar{x}) \right\rangle, \text{ for all } \xi^U \in \partial^* p^U(\bar{x}), \text{ and } \nu^U \in \partial^* q^U(\bar{x}).$$

From hypothesis (ii), we get

$$\sum_{i=1}^{m} \bar{\mu}_i h_i(x) - \sum_{i=1}^{m} \bar{\mu}_i h_i(\bar{x}) \geq \left\langle \sum_{i=1}^{m} \bar{\mu}_i \zeta_i, \eta(x, \bar{x}) \right\rangle, \tag{30}$$

for all $\zeta_i \in \partial^* h_i(\bar{x}),\ i = 1, 2, ..., m.$

On adding (28)-(30), we have

$$\bar{\lambda}^L [p^L(x) - \phi^L(\bar{x}) q^L(x)] + \bar{\lambda}^U [p^U(x) - \phi^U(\bar{x}) q^U(x)] + \sum_{i=1}^{m} \bar{\mu}_i h_i(x)$$

$$- \left[\bar{\lambda}^L [p^L(\bar{x}) - \phi^L(\bar{x}) q^L(\bar{x})] + \bar{\lambda}^U [p^U(\bar{x}) - \phi^U(\bar{x}) q^U(\bar{x})] + \sum_{i=1}^{m} \bar{\mu}_i h_i(\bar{x}) \right]$$

$$\geq \left\langle \bar{\lambda}^L \left[\xi^L - \phi^L(\bar{x}) \nu^L \right] + \bar{\lambda}^U \left[\xi^U - \phi^U(\bar{x}) \nu^U \right] + \sum_{i=1}^{m} \bar{\mu}_i \zeta_i,\ \eta(x, \bar{x}) \right\rangle,$$

which by (27), yields

$$\bar{\lambda}^L [p^L(x) - \phi^L(\bar{x}) q^L(x)] + \bar{\lambda}^U [p^U(x) - \phi^U(\bar{x}) q^U(x)] + \sum_{i=1}^{m} \bar{\mu}_i h_i(x)$$

$$\geq \left[\bar{\lambda}^L [p^L(\bar{x}) - \phi^L(\bar{x}) q^L(\bar{x})] + \bar{\lambda}^U [p^U(\bar{x}) - \phi^U(\bar{x}) q^U(\bar{x})] + \sum_{i=1}^{m} \bar{\mu}_i h_i(\bar{x}) \right],$$

that is

$$L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}) \leq L(x, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}). \tag{31}$$

On the other hand, using the feasibility of $\bar{x}$ of the problem (NFIVP) and the fact $\mu \in R_+^m$, we have

$$\mu_i h_i(\bar{x}) \leq 0, i = 1, 2, ..., m, \tag{32}$$

By using (32) and the optimality conditions (5), we get

$$L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \mu) \leq L(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu}). \tag{33}$$

By inequalities (31) and (33) we conclude that $(\bar{x}, \bar{\lambda}^L, \bar{\lambda}^U, \bar{\mu})$ is a saddle point for $L(x, \lambda^L, \lambda^U, \mu)$. Hence the proof. ∎

5. Conclusion

In this paper, with the idea of convexificators, we have discussed optimality conditions and saddle point criteria for a nonconvex fractional interval-valued optimization problem. Also, we provided an example to validate the results of sufficient optimality conditions established in this paper. In our opinion,

the techniques employed in this paper can be extended for proving the similar results for other classes of fractional programming problems with the functions involving are convexificators. This may be the topic of some of our forthcoming papers.

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"A CATASTROPHE TO MIGRANTS IN TELANGANA STATE" - MOBILITY AND PATTERN DURING COVID - 19

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ABSTRACT

Indians are constantly migrating as a result of the nation's internal population boom, which is also changing how the cities look. India has emerged as the primary destination for migrant labor due to its rapidly growing GDP, population, and urbanization rate. Many rural residents of various Indian states have turned to migration as a means of securing their daily bread. It is connected to the economic activities that cause both intrastate and interstate migration. An analysis by the World Economic Forum indicates that there are 139 million migrant workers living in the nation. The majority of migrant workers who travel to southern India come from northern states. Since more than ten years ago, this has been considered standard procedure. Workers from Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh, and Odisha move to the southern states where they are mostly employed in the manufacturing and construction sectors. Civil society organizations estimate that over 15 lakh migrant workers have settled in Telangana, the majority of whom work in manufacturing, food production, and construction. A sizable portion of migrant workers were drawn to Hyderabad by the real estate and IT booms, and many of them have since settled there. The Sultan Shahi neighborhood, which is close to the Charminar, Secunderabad, Nallakunta, and Tolichowki, is where most of Hyderabad's migrant workers addas—also known as labor addas—can be found. India was one of the first nations to implement the initial COVID-19 lockdown, but the lockdown was ineffective, and within a few months, India was added to the list of nations that had been most severely affected by the coronavirus epidemic. More than the general populace, the virus more severely affected migrant workers and daily wage earners in India. The Indian government's COVID-19 lockdowns hurt migrants. Because so many of the migrant workers were unable to earn their daily wages during the lockdown, they were unable to purchase enough food to eat each day. This made the crisis' many aspects worse while also having an impact on the social and psychological health of migrant workers. The Telangana State Department of Labour was in charge of putting in place various programs for migrant workers, but due to a lack of resources and expertise, these programs were unable to handle the emergency. The purpose of this paper is to provide more information about the movement and actions of migrant workers during COVID-19 in Telangana.

Keywords - *Migrant Workers, Lockdown, implications, Informal economy, sustainable growth*

INTRODUCTION

John F. Kennedy: "The world is very different now. For man holds in his mortal hands the power to abolish all forms of human poverty, and all forms of human life".

The present-day world is very different. Because man has the ability to end all forms of human life and all forms of poverty in his mortal hands. One of the world's cities with the highest density is Telangana. Telangana has taken in a lot of migrant workers as a result of its tightening fiscal policies. Since the 1900s, when real estate prices were at their peak, residents of Telangana have become more frugal. According to estimates from civil society organizations, there are about 15 lakh migrant workers, the majority of whom work in the food, manufacturing, construction, and other sectors. who now call Telangana home. It used to be a large migrant worker community. Despite having a sizable impact on the economy through their labor, migrant workers were not included in the government's many benefit programs. An estimated 80% of the workforce consists of migrant workers. According to the legend, they are the anonymous contributors. Only 38.6 percent of Telangana's 3 point 8 crore residents, with Hyderabad constituting the majority, lived in urban areas in 2019. Due to increased urbanization and conditioning from experimentation, it is expected that the aforementioned numbers will rise. Hyderabad's population is, according to data from 2019. Data from 2019 shows that Hyderabad, a megacity with a population of 1,7 million, has 1,476 slums and 24 interstate settlers. With an expected 10 million residents in 2020, Hyderabad is India's third-busiest megacity, with a population viscosity of 18,480 people per forecourt kilometer (47,000/sq mi). Following that, COVID-19 suddenly materialized and spread. Worldwide, including in India, COVID-19 has developed into a problem and a source of empirical distress for millions of people. It has an adverse effect on the quality of life for many people along with the health of the populace and a number of thriving industries. Significant changes have been made to the migrant workers' way of life in the country. Workplace chaos was not acceptable every day. Numerous migrant worker groups that were left stranded in Hyderabad included women and their children. The workers were concerned because food supplies were running low and there was no indication of a plutocrat. Because their places of employment have closed and they have no other source of income, the Telangana government's department of labor gave them 12 kg of atta, or rice, and Rs 500 in cash along with a sign warning landlords not to make them pay rent. eSHRAM is a venture of the Pradhan Mantri Shram Yogi Maandhan Yojana. eSHRAM. The eSHRAM portal was developed by the Ministry of Labour and Employment to give them the best chance to find employment and to make social security benefits available to them. Despite the fact that both the federal and state governments have implemented a number of programs to assist migrant workers during this crisis, not all of them have been successful, and some have resulted in significant income losses. They were in a terrible situation because they didn't have access to transportation and couldn't get to Chuck. To help the workers who had families, the government eventually gave them 12 kg of rice or atta and Rs 500. According to data from the state labor department, more than 27,260 migrant workers from Chhattisgarh, Odisha, Uttar Pradesh, and West Bengal have reportedly left Hyderabad. 3240 employees who had previously worked in other parts of the state have also moved back to their original townlets. Emigrant workers reported, "Last time during the lockdown, we were stuck there for more than two months," in a check that was conducted. ". However, some people assisted us in that area. We're not actively looking for help this time, either. This exploratory paper's goal is to learn more about migrant workers' movements and behaviors during the COVID-19 pandemic in light of the current situation.

SIGNIFICANCE

Migration consistently makes sense when it comes to cost, regardless of how ignored it is. According to a current IMF Ponder, both tall- and moo-declared specialists who relocate over the long run benefit their unused domestic nations or the nations of the nation by factoring in salaries for each individual and living standards. In addition to filling the basic jobs for which the local laborers have little demand, both tall and moose declared wanderer specialists bring various benefits to the nation or nations and also give the natives the opportunity to work at advanced-declared jobs. Additionally, the nation's citizens share in the profits

in a universal way. The nation's living standards and the Net Residential Item (GDP) are both raised by movement and transitory professionals, who are considered the quiet providers of the cheapness. Relocation is supposedly a blessing because it increases work efficiency while also making labor more affordable. The appearance of temporary workers is said to have an impact on individual income. Over the past 40 years, India has experienced the largest internal movement of any country at any time. Temporary specialists increase GDP. India's GDP growth has outpaced that of the decade before in each of the last five decades. In India, internal relocation affects 100 million people, or 3% of the population, according to the 2017 Productivity Study. e. About one-fifth of India's labor force is constrained. The combined annual profit of India's insider wanderer specialists is around $170 billion. e. approximately 6% of India's GDP. It implies that only 2% of India's GDP is actually being traded. Despite the fact that tall-declared relocation benefits more the average pay of best workers, substance is cosmically taken an interest in. An increase within the temporary share benefits both the foot 90% and the best 10% of workers' normal pay per individual. When compared to the bottom 90 percent of earners, the proximity of pioneers doesn't seem to widen the income gap. Temporary specialists' salaries earned abroad and the investment money they make with their pay are important factors in the adjustment of their home countries' installments. They eliminate the regularly occurring adjust-of-payment poverty, thereby reducing the gap in international trade. Thanks to settlements, the customarily significant restriction imposed on the productive improvement of the settlers' domestic countries by the adjustment of installment poverty can be made possible. They have a more favorable impact on the adjust of installments than other financial inrushes (comparative to coordinate ventures or advances which would have the same impact in absolutely checking terms) because they bear no interested, do not need to be reimbursed, and their use is not tied to specific venture frameworks with a high purport substance.

OBJECTIVES

- To examine the impact of COVID - 19 on migrant workers with reference to Hyderabad
- To analyse the mobility of migrant workers in the informal economy
- To investigate the occupational reasons and challenges faced by migrants in the informal economy.

Research Methodology

The data for this study is retrieved through secondary data-ILO Reports, Surveys, Websites, Social Media sites and as it is a review paper, the information for the pattern and movement of migrant workers is also browsed from quality indexed journals

RESEARCH OBJECTIVE-1
MIGRANTS IN PANDEMIC - BOON OR BANE
Migration of migrant workers to India is unquestionably not a modern marvel. It generally exists and could be used with caution. The migration strategy just so happens to occasionally alter as a result of monetary changes. The continuing rise in migration rates may be attributed to dissociating factors. Due to factors like desperation, a lack of job opportunities in common locations, regular debasement, and so forth, they were forced to leave their home country and emigrate to other locations in order to find work. On the other hand, metropolitan zones' mechanical and benefit-creating sectors offer low-paying jobs related to improvements in education, transportation, and correspondence—all underutilized elements that support spatial flexibility. Therefore, the point of interaction of various factors, such as the push and drag factors, within the course of progress cannot, strictly speaking, be seen as affecting the speed of versatility, but would rather encourage advancement of current development plans. This raises the question of figuring out whether the oppressed and constrained region is being driven by the changing economic structure or if the characteristics of the better off pack are having more of an impact than the movement's growing float. As a result, it calls for a crucial evaluation of

the strategies and plans for India's development over the ensuing years. In order to understand and ascertain the movement situation in India, the show paper aims to obtain a comprehensive relocation plan in India. An IIT Hyderabad researcher claims that national-metropolitan movements needlessly target those at the top of the social and economic food chain in cities, even though nearly 78 percent of those who are homeless in common Bihar are moving in that direction. These temporary employees frequently hold advanced degrees and depart the area without making a significant contribution to the local natural economy. This respectably popular - off migration stream is distinct from the other, more erratic development stream, in which experts primarily engage in manual labor and are likely to work in provincial districts after moving. These isolated transient work market pathways suggest that objective districts should analyze social and financial trends in source regions. Depending on their place in the town's social and economic hierarchy, each individual will accept a different kind of work as the development's goal. Hyderabad cannot boast of having a significant number of temporary experts in the IT and creation sectors like other cities can. Although these states are assumed to be the obvious ones where temporary workers originate and reside in Hyderabad, the majority of temporary workers in Hyderabad come from states like Uttar Pradesh, Bihar, West Bengal, Odisha, and many others. Over the course of a significant amount of time, there has been a progressing entry between the aforementioned states. Over time, there will be changes to the temporary experts' plan. Due to adjustments made to the plan, it keeps changing from between times to breaks in much the same way that the management of the temporary experts does. According to reports, the way temporary employees are managed has changed. Hyderabad's growing manufacturing and IT industries are thought to be responsible for the city's shift in the makeup of temporary workers. According to reports, there has also been a significant increase in the amount of certifiable space, which has increased the development industry and changed how temporary workers are managed. A significant change in the plan was made in the later period as a result of the Coronavirus-19 pandemic. As a result of the infection episode, many temporary workers from Hyderabad left the city and went back to their home communities, where there had been a change in the growth of skilled workers. Data shows that over the years, over 2,000 people have visited their hometowns. Employees from clear states who had traveled to Hyderabad because of the disease outbreak have returned, which has significantly changed the temporary trained professionals' strategy and motivations. .

Let us understand the key role of migrant workers in major sectors of the economy:
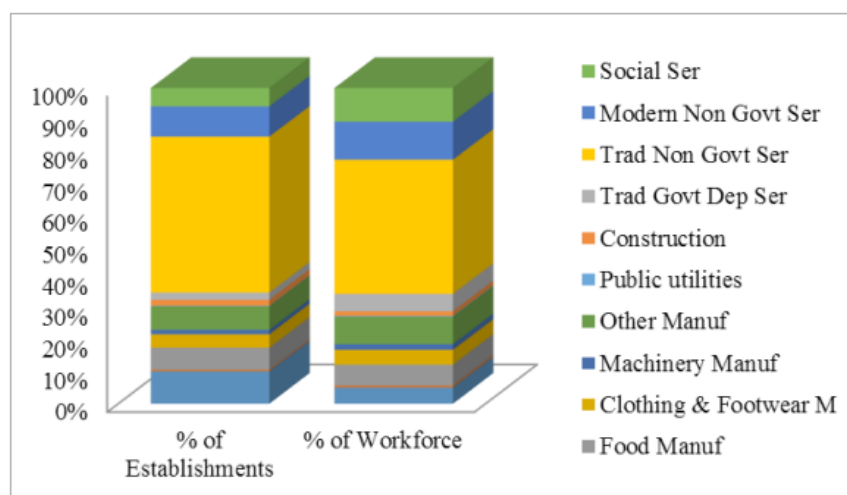
Breakdown of employment in Hyderabad urban agglomeration

- Everyone experienced an uncertain crisis during the lockdown that no one could make up for. Both migrant workers and daily wage employees suffered as a result. Major construction companies made all necessary arrangements for the migrant workers' stay at the construction sites or other locations, as well as provided them with food, medical care, and other necessities. A Confederation of Real

Estate Developers Association of India (CREDAI) Telangana unit member claimed, "They have been successful in persuading a significant number to stay back."

- Bihari migrants made up more than 90% of the workforce in Telangana's rice mills. These workers, who assemble and disassemble rice trucks, had traveled to Bihar for Holi but were stranded there because of the lockdown. The construction industry in Telangana employs the majority of the 8.5 lakh migrant workers there.

- Now we can understand the key role of migrants as they contribute over 70 percent of the workforce in the construction sector in Hyderabad and surroundings are migrant workers, mostly from Bihar, Jharkhand, Uttar Pradesh, Chhattisgarh and Odisha.

- Out of these 8.5 lakh migrant workers, highest 26%, were from West Bengal, 20% from Jharkhand, 18% from Bihar14% from Odisha, while 3% were from Chhattisgarh

- Many tiny and small-scale businesses in the engineering sector with five to thirty employees are included. In Kattedan, there are also a few sizable buildings like biscuit factories and power looms. There are several hundred workers in biscuit factories. There are also a few waste recycling facilities.

City	Sex	Engineering	Construction	Services	Total
Hyderabad	M	84	78	91	253(84.33)
	F	16	22	9	47(15.66)
	T	100	100	100	300(100)

- Migrant workers also have two sides, just like a coin. There is a flip side to the coin, however, as daily wage workers and contract limited deals are very uncertain. Migrant workers contribute to the growth and development of the informal economy in previously unheard-of ways, and most importantly, millions of migrants have a means of support. Migrant workers lost their means of subsistence during periods like COVID-19, which no one could have predicted and which had an impact on millions of lives. They were left without food and shelter.

- Therefore, migrant workers are a blessing if properly organized and put into a workflow because they help to develop and grow the informal economy, but they are a curse if not acknowledged and ignored because they increase poverty, unemployment, and illiteracy rates across the country.

RESEARCH OBJECTIVE -2
ARE MIGRANTS WORKERS PART OF INFORMAL ECONOMY…………….???
There is an urgent need for work movement in India in order to promote positive development and to maximize people's socio-productive states. Over 500 million people work regularly in India. More than 73 of them relocate to new countries in search of secure employment. They are required to work in abhorrent conditions and have virtually no access to social welfare programs. They endured a great deal at various points in the back movement. Studies show that a lack of planning caused productive problems like compensation envelope theft, conservations, a lack of government-sponsored retirement, boss liability, versatility problems, and a sizable social divide. The division model is only partially credible according to observational validation, and

the movement cycle predicted by probabilistic models does not seem to make sense in that southern mindset. Real and certain versatility from the casual to the conventional area was low; schooling and municipal experience were granted at comparable rates in the two areas; additionally, instruction was one of the major factors affecting versatility between areas. More than half of the participants from the casual area had moved to Telangana because of job opportunities there. Urban pilgrims are estimated to number 21, or roughly 32 lakh, during the time of the plague, when the world saw a significant change in how people went about doing their jobs, including Public Organization of Work, Financial Matters, and Innovative Work. Because movement expands the labor pool in some thrifty industries, it has an effect on the workforce. It is likely that interest in employment will rise as pilgrims increase consumer interest in particular services and goods. Due to this, there might be more competition for existing positions in word-related fields, but there might also be room for new ones to emerge. The emergence of a casual moderation in most developed countries has prompted the link between thriftiness and rules. The term "casual thriftiness" describes people who create pay outside of the state's nonsupervisory boundary but who also include analogs inside that boundary. Casual thriftiness's persona and compass are defined by the nonsupervisory outline and how it relates to appropriate moderation, or effort that produces benefits. The activity and energy of urban casual thriftiness depend on portability. Casual agents who work in local communities and identify spaces with specific needs or a general lack of the norm depend on their versatility to carry out their business operations. While some organizations run out of set locations, others are very mobile and run all over the city on different days or at different times of the day. The pioneers typically work in the unorganized area of cities because they lack the credentials needed to obtain positions there. Due to this, there is an increase in the need for paired work in the neighborhood. On the one hand, there are the irregularly paid workers who are not protected by any type of government-managed retirement, and on the other, there are the largely declared and better paid workers in the traditional area. The Telangana State is well known for having a large population of sloppy/casual pool dwellers. Approximately 94 percent of the pool is in the disorderly area, according to the Public Commission on Work in the Disorderly Area (NCEUS, 2007). The majority of workers in these areas abhor government-sponsored retirement (nurturing instincts and medical services benefits, pension, etc.) as well as business security (no assurance against erratic overt repetition), work security (no assurance against accidents and illness at the factory), and both.).). The Telangana Building and Other Development Laborers Welfare Board (TBOCWW Board), which was established by the public authority of Telangana under area 18 of the BOCW act 1996, is in charge of ensuring the welfare of development laborers. The Telangana government's public authority established the board, which took effect on September 17, 2014. The board approves a strategy to speed up the hiring of construction workers as well as the selection and support of cess. the Telangana government board in charge of overseeing the social insurance and credentials of development laborers. The 54 development studio jobs that the board has listed in its illustration are covered by the demonstration and are therefore eligible for all benefits. The board has Rs 613 crore to put the development workers' welfare plans into action. Demands for peaceful community work are declining as urban casual areas become more necessary for the development of urban areas. Peaceful workers' transition from farm to non-ranch molding is an accretive interaction that fuses the needs of the community with peaceful work.

Research Objective-3

SWOC ANALYSIS OF MIGRANTS WORKERS

COVID-19 a catastrophe that mankind never expected with current technology and predicting the future. There is a huge uncertainty about how long this crisis will last and what damage it would do to the economy, livelihood of people and availability of basic healthcare services.

STRENGTHS -

Before any laws or policies are renewed or passed, data must be collected on migrants and workers in the informal sector by gender and age. When gathering the most recent data, it's crucial to make sure that nothing is overlooked. It's possible that data on these migrant workers wasn't always collected and stored. Data collection on migrant workers has developed into a crucial component. In order to safeguard the rights and way of life of migrant workers, many of whom suffer adverse effects from the pandemic, the government has taken the initiative to compile the data and suggest new families. The migration data portal has made data regarding COVID 19's effects available. The majority of people affected by COVID 19 in nations like India and about 12 percent of migrant workers worldwide are over 65, according to the study. Despite the fact that the lockdown measures have had an impact on migrants of all ages.

WEAKNESS -

A sizable portion of the migrant workforce consists of subsistence farmers. Furthermore, they were not in dire need simply because they were able to find migrant work. Most migrant workers were unable to transport their belongings once the conflict started, so they left them in their home or country of origin. Professionals lost a lot of their jobs. A significant number of workers lost both their homes and their jobs in both their own country and the country where they resided or worked. As a result of the Indian government's ignorance of their situation, many of them struggled to return to their original homes and were left without assistance. Migrant workers experienced unfavorable working conditions as a result of the pandemic. One of the main concerns with regard to migrant workers is the COVID-19.

OPPORTUNITIES –

Even though COVID-19 had a lot of drawbacks or adverse effects on migrant workers, there was one thing that stood out as being beneficial. Before the COVID-19, there were few laws protecting the rights of migrant workers, and the government did not put forth many beneficial policies. Few people are aware of the importance of migrant workers and the crucial role they play in sustainable development, particularly in the informal economy. Most people had no idea what migrant workers did to the economy. Migrant workers are now at the center of public conversation thanks to the COVID-19 pandemic. The government has begun to suggest new laws and regulations to protect migrant workers in the future in response to the pandemic. policies like providing the migrant workers with fundamental service systems like health care. Politicians now ensure that immigrants are properly considered when formulating plans for a coordinated national response. Future COVID-19 waves and other health and humanitarian crises involving migrant workers will call for long-term plans and sizeable public investments.

CHALLENGES -

Governments have been shocked by the suddenness of the widespread illness with such a high number of cases and fatalities, on the one hand. On the other hand, little was understood about the illness and how it spread, and control is still being improved.

The lack of logical data that could sufficiently illuminate a response to the widespread has affected the development of policy. Given its size and spread, managing vagrants while in lockdown speaks to a huge calculated challenge. Some of these issues can wait, while others need immediate attention.

1. Currently, there are several problems with resettlement or stranded transients.
   - How to manage waste and provide cleaner, water, latrines, and food while maintaining excellent sanitation and hygiene in all camps and shelters.
   - How to offer the general public basic medical care and preventative tools (like gloves, sanitizer, and other items).

- How can the potentially contaminated people be quickly identified, screened, and isolated separately?
- How can the social separation between migrants be kept in order to stop the disease from spreading?
- .How can we assist the homeless people who require counseling and psychological support?

2. A real database for the homeless people who are stranded in cities, thruway camps, and goal areas must be created immediately. Information on the quantity and characteristics of vagrants (in camps, domestic isolate) is required for future administrative requirements as well as to exchange the benefits of social welfare plans at the event.

3. The general public contributed to lowering the risks for migrant workers by promoting laws like coincidental scope, workmen's compensation, welfare protections, and life insurance, which can give them and their families financial support. Incentives like these can be offered by employers to show how much they value their staff members, which will boost their motivation and loyalty. As a result, there will be a reduction in representative attrition of more than 20%.

4. In India, the casual workforce consists of more than 150.6 million regular wage earners. Most of these specialists are not aware of their responsibilities as "migrant workers" under the law. ". Because of this, migrant workers are frequently subject to control, distortion, and underpayment.

5. Vagrants blend in more in their new environment, where they also happen to reside. They are more susceptible to various types of social, mental, and emotional trauma in these circumstances because they fear being shunned by the community and worry about the safety and security of their families there. Travelers are compelled to leave their hometowns in search of better opportunities and profit, sometimes leaving behind their families.

CONCLUSION

The COVID-19 spread and lockdown have had a significant effect on migrant workers because of their employment and pay misfortunes. Due to this, it is possible to see how frequently temporary workers' designs change and how stray workers are placed in new locations. After their return, the vagrant experts are now coping with a number of issues. Their need for employment opportunities is one of the urgent problems. After returning, the migrant workers are currently coping with a variety of issues. Lack of employment opportunities for them is one of the main issues. And a lot of the employees only get paid moo. because there are incredibly few jobs available. There is no doubt that temporary workers now make less money each month. Their income or the economy aren't really impacted, but their mental health is. They are residing in abjectly miserable conditions. Their projected unemployment rate in the future may be seriously concerning from a financial standpoint. Despite the fact that they are supposedly the unsung heroes and make a sizable economic contribution, they are still ignored. We briefly discuss relocation in India, go over significant government relief efforts, and list the Incomparable Court's instructions for the population of vagrants in relation to the lockdown. As a result, we can see that there have been significant modifications made to both the construction of temporary workers and the shifting movements of stray professionals. The temporary employees' return has resulted in a number of issues that they are currently resolving. They need opportunities for employment, which is one of the urgent issues. And many professionals are working for extremely low pay rates because there are so few job openings. For migrant workers, the government must specify modern arrangements. People need to be aware of their significance, how they advance and raise GDP, and how they impact the unofficial economy.

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దిగంబర సాహిత్యంలో సామాజిక స్పృహ

డా. ఉదాలి విష్ణుప్రియ, తెలుగు విభాగాధిపతి, సెంట్ ఆన్స్ మహిళా కళాశాల, మెహదీపట్నం, హైద్రాబాదు.

పతితమైన జాతికి మానవత్వాన్ని రుచి చూపేందుకు, అవసరమైన జాగృతిని కలిగించేందుకు చేసిన ధ్వంస రచన దిగంబర కవిత్వం. మానిషాద శోకం లోంచి, వేదనా వల్మీకం నుంచి ఆవిర్భవించింది. మంచిగా ఆకాశంలా అవనిలా మనిషిలా బతకాలి. ముందు మనం మనుషులం. మానవత్వాన్ని ప్రతిష్టించే మానవుడైనా మహర్షి కొరకు అన్వేషణ. మనిషి దేనికీ బానిస కాకూడదు అంటూ తమ పంథాలో మేం మేముగానే వస్తున్నామని దిగంబర కవులు తెలుగు సాహిత్య లోకంలోకి ప్రకటించారు. మానవత రెండు కళ్ళు మూసుకుపోయినై. అప్పుడు మూడో కన్నుగా విప్పుకుంటూ తుఫానుగా వచ్చిందే మా ఉద్యమమని ఎలుగెత్తి చాటారు దిగంబర కవులు. 1965 నాటికి మన రాష్ట్రంలోనే కాదు భారతదేశంలో కూడా రాజకీయ, సామాజిక పరిస్థితులు అధ్వాన్నంగా ఉన్నాయి. అప్పటికి స్వాతంత్ర్యం వచ్చి పద్దెనిమిది సంవత్సరాలైంది. ఈ నేపథ్యంలో 1965 లో దిగంబర కవితోద్యమం వచ్చింది. అభ్యుదయ కవితా ధోరణిపై తిరుగుబాటుగా సమాజంలో క్షీణిస్తున్న మానవీయ విలువలు, వాటి పట్ల కసి, అక్కసుతో ఈ ఉద్యమం పురుడు పోసుకుంది.

> మనిషిలో అట్టడుగున బురదగుంటలో
> పడివున్న మనిషిని లేవదియ్యడం
> ఎముకల లోతుల్లో ధ్వనించే
> స్వచ్ఛమైన గీతాల్ని ప్రతిధ్వనించడం
> కళ్ళ వెనుక దాగి వున్న
> సిసలైన కన్నీళ్ళని ప్రసరించడం
> గుండెల తీరాన్ని కొట్టుకునే
> సహజమైన భావాల్ని ఒడుపుగా పట్టడం
> పెదాల కొసల్లో
> చిక్కటి చిరునవ్వుల్ని మొలిపించడం
> నిజాన్ని నిజంగా నగ్నంగా చెప్పడం...

ఇదీ వీరి అజెండా.

మనీష అనగా బుద్ధి. అది కలవాడు మనీషి. మానవునిలో బుద్ధి ఉన్నది. అది యుక్తాయుక్తాలు, ధర్మాధర్మాలు, యోగ్యతాయోగ్యతలు మున్నగు వాటిని విడమరచి చూపుతుంది. బుద్ధి ఇంద్రియం పని చేయకుంటే మానవునికి యుక్తాయుక్త పరిజ్ఞానాలు లోపిస్తాయి. బుద్ధి ఇంద్రియము కలుషితమైనా కూడా ప్రమాదమే. ఇక్కడ దిగంబర కవులు మానవుని బుద్ధి అట్టడుగున పంకిలంలా పడి ఉందని భావిస్తున్నారు. ముఖ్యంగా రాజకీయ నాయకులు, మఠాధిపతులను దిగంబర కవులు వారి భావజాలంతో దూషించారు. వీరి కవిత్వానికి అలంకారిక సిద్ధాంతం అన్వయించదు. తన్మతానుసారముగా వీరి కవితను పరీక్షించడానికి వీలు లేదు. ఎందుకంటే మూల సిద్ధాంతాలకు వీరి ఆదర్శాలకు ఎక్కడా పొత్తు కుదరదు.

రసాల సొలెగూళ్ళను చీల్చలేక

అలంకారాల అంధకార మార్గాల్ని ఛేధించలేని,

సమకాలీన వెలుగు వారధిని గాంచలేని

చీకటి బానిసలు, గుడ్లగూబ లు...

అని జ్వాలాముఖి పై కవితా పాదాల్లో వ్యక్తి స్వేచ్చకి ప్రముఖ స్థానాన్ని కల్పించాడు. దిగంబర కవులకి మార్క్సిస్టు దృక్పథం మీద గౌరవం ఉండటం కనిపిస్తుంది. జ్వాలాముఖి రచించిన ఓటమి– తిరుగుబాటు అనే ఖండికలో కవి ఇలా ఉటంకించారు.

"దైన్యంతో దిగజారిన పశువు సైతం

ఆత్మహత్య నాశ్రయించదు

మనిషి ఓటమి ఆత్మహత్య"

ఈ పాదాల్లో మనిషి చేసుకునే ఆత్మహత్య పిరికి చేష్టకు నిదర్శనమని కవి భావన.

"ఓటమి తిరుగు బాటు చేయాలి

ఆత్మ హత్యా తిరగబడి హత్య చేయాలి"

అనే కవిత్వ పంక్తుల్లో విప్లవాత్మక ధోరణి దొర్లుతోంది. తీవ్రమైన ఆవేశం ధ్వనిస్తుంది. నిద్దుర మత్తులో మగ్గుతున్న మానవ లోకానికి విప్లవ శంఖారావంలా ఈ మాటలు వినిపించాయి. అయితే వీరి కవిత్వంలోని ఈ పంథా ఎక్కువ కాలం నిలవలేదు.

'కుష్టు దేవుళ్ళు' అనే కవిత్వ ఖండికలో నగ్నముని నిరాశా ధోరణితో రాసిన పాదాలు గమనిద్దాం...

"ఎప్పటికీ మనం తిరగబడలేం కాబట్టి,

ఎప్పటికీ మనకి తిరగబడడం చాతకాదు కాబట్టి

మన రక్తం నిండా కులాల మతాల మాత్రం ప్రవహిస్తున్నది కాబట్టి

మనం పిరికి కుక్కలం పందులం కాబట్టి

మన జీవితాన్ని శాశ్వతంగా కొనేసి పరిపాలిస్తున్న

రక రకాల కుష్టు దేవుళ్ళని కొలవదానికి అంకితమవుదాం"

మానవునిలో నిద్రాణమైన అలసత్వాన్ని కవి తన భావజాలంతో మేల్కొలిపారు. కానీ ఇక్కడో విషయాన్ని గమనిస్తే ప్రస్తుత సమాజానికి కూడా ఇవి వర్తిస్తాయనడం అతిశయోక్తి కాదు. ఎప్పటికప్పుడు మానవుడు అన్యాయాన్ని ఎదిరించే ప్రయత్నం చేస్తున్నా రాజకీయ సొలెగూళ్ళు మానవుడిని ఎటూ కదలనీయకుండా కప్పేస్తున్నాయి.

నిఖిలేశ్వర్ గారు రాసిన "రైతన్నలకు విన్నపం" అనే కవిత్వంలో..

"ప్రపంచీకరణ లావాదేవీలలో

'పేదరికం' నిర్మూలన ఇపుడు ఒక వ్యాపార సరకు

ధాన్యం పండించే వాడే దీనంగా

నిలువుదోపీడీకి కూలుతున్నాడు

ఈ దళారీ మార్కెటింగ్ వ్యవస్థలో..."

పై కవితలో ప్రతి వాక్యం ప్రస్తుత సమాజానికి ఓ నిలువుటద్దం!

"రుణ మాఫీ లెక్కల్లో

వెన్నెముక విరిగిన రైతన్న

ప్రతి ఎన్నికలకు ముందు

ఆ తర్వాత పాలకులు విసిరే బిక్షాపాత్రతో

ఎరువుల నల్ల వ్యాపారుల ఎదుట క్యూలలో సొమ్మసిల్లుతున్నాడు.

'ఆకలి'ని బేరమాడుతున్న

నల్లధనం కుబేరుల ధనాగారాల్లో

మూలుగుతున్నది ఈ పుణ్యభూమి"

అంటూ రైతు పడే ఆవేదనను పట్టించుకోని ఈ సమాజాన్ని నిలదీస్తున్నాడు కవి.

మనిషి మనుగడకు మూలం ఆహారం, రైతు. ధాన్యం పండించే ఆ రైతు కన్నీళ్లు తుడిచేదెవ్వడంటూ –

ప్రతి గింజపై తినే వాడి పేరు రాసి పెట్టారనేది ఒకనాటి నమ్మకం

పండించిన గింజలు చేతికి రాలేదనేది ఈనాటి ఘోష

ఇక యువ రైతాంగ రక్తంలో

తరతరాల పోరాటాల వారసత్వం మేల్కొనాలి

ఇప్పుడిక సమష్టి ఆయుధమే భూమి పుత్రుల ధైర్యం

ఆత్మహత్యలకు బదులు ఆత్మవిశ్వాసంతో చేయూతనిచ్చే ఉద్యమాలు రాగాలలి అంటూ కవి ఇక్కడ రైతు సమాజాన్ని మేల్కొలుపుతున్నాడు.

నిఖిలేశ్వర్ గారి మరో కవిత్వం "మిగిలిన ఆకాశం కింద" అనే కవిత్వ ఝురిలో...

మెగాసిటీ మెర్క్యురీ వెన్నెల్లో

నిద్రాపావురాన్ని నిలువునా మింగుతున్న

చలి కొందచిలువకేం తెలుసు కారుణ్యం?

వెన్నెముకలోంచి వణికే ప్రకంపనాలు

పేగులను తిరగేసి ఊపేయగానే

డొక్కలో ముదుచుకోవాలన్నా సొంత గూడేది?

వలసొచ్చిన దిక్కులేని పల్లె బతుక్కి

పరాయి గుప్పిట్లో రోజువారీ ఊపిరి

ఆకలి దప్పుల అవిరామ సమరంలో

చెల్లాచెదురైన వృత్తుల చిరునామాలు...

పలు వృత్తులను ఆశ్రయించి బ్రతుకుతున్న ఎంతో మంది ప్రజలిప్పుడు బతుకుతెరువు కోసం పట్టణాలకు వలస వెళుతున్నారు. వారి ఆకలి దప్పుల వెనుక వారి చేతివృత్తులు కనుమరుగయ్యాయి. ప్రస్తుత సమాజంలో పల్లెటూళ్ల నుంచి వచ్చి తలదాచుకునేందుకు కూడా అవకాశం లేని దీనావస్థను కవి వర్ణించిన తీరొకసారి చూడండి –

"ఇప్పుడిక మిగిలిన అనంతాకాశం కింద

గింజుకుంటున్న పాలిథీన్ గోతాం సంచుల కింద

ఆరాటంగా తల్లడిల్లుతున్న అవయవాలను

ఈ రాత్రి మంచు బ్లేడు చల్లగా కసిగా కర్కశంగా చీలుస్తూ

తారు రోడ్డు పక్కలో దయతలచే ఆ కాసింత గడ్డిపై

మళ్ళీ మరో సంవత్సరం అంతే నిర్లక్ష్యంగా

నెత్తురోడ్చి నిట్టూర్పు కూడా వినపడనివ్వదు..

అంటూ మారని నిరాశ్రయుల బతుకుల బాధలు వర్ణనాతీతం అని అంటాడు.

ఎవరి చెవులకు వీరి ఆర్తనాదాలు చేరుకోవా... చివరికి ఆ దేవునికి కూడానా? అంటూ ఆవేదనగా ప్రశ్నిస్తాడు.

> ఎన్ని కబుర్లు చెప్పినా
> ఎన్ని ఆర్థిక సూత్రాల వ్యాఖ్యానాలు వల్లించినా
> ఇక్కడి శ్రమ సారమంతా
> నల్లడబ్బు కొవ్వుకు నీలికాంతులద్ది
> అంతే అట్టహాసంగా ఆకాశంలోకి ఈ కంకర గుట్టలు
> అంతే ఆర్ష సాంప్రదాయానుసారంగా
> సంధ్యావందనం చేస్తున్న కొత్త సంవత్సర-
> భక్తుల సందోహంగా తిరుపతి కొండపైకి
> మార్మోగే ఆర్తనాదంలా చర్చి గంటల్లోకి
> విలవిలలాడే దీన విలాపంలా అల్లా దయలోకి!

సమాజంలో పేరుకుపోయిన కల్మషాలను నగ్నముని నిర్దాక్షిణ్యంగా బాహాటంగా తనదైన శైలిలో తెలిపారు. పట్టపగలు జరుగుతున్న అన్యాయాలు అక్రమాలు అమానుషాలు ఉన్నదున్నట్లు చెబితే నీకు అశ్లీలంగానే కనపడుతుంది.. అంటూ –

> "అశ్లీలత అంటే ఏమిటి..
> నల్ల బజార్లు పగటి బజార్లకంటే
> రొమ్ము విరుచుకు రోడ్లపై నడుస్తున్నాయంటే
> నీకు అశ్లీలంగానే వినబడుతుంది
> తోలు వ్యాపారస్తులు
> నీతి బోధలు చేస్తున్నారు.. రా అంటే
> నీకు అశ్లీలంగానే వినబడుతుంది..!"

ఇప్పటికీ ఈ సమాజంలో నల్ల బజార్లలో జరిగే విన్యాసాలు మనం కంటున్నాం. వార్తల ద్వారా చూస్తున్నాం. సిగ్గుతో తలెత్తుకోలేని వార్తలైనా చివరికి వాటికి తగిన న్యాయాన్ని చేకూర్చక పోయినా అది జోరున వర్షం పడి ఆకాశం ఏమీ ఎరగనట్లు ఎలా గుంభనంగా ఉంటుందో మన సమాజంలోని మానవుడూ అలాగే ఈ సంసారాన్ని నెట్టుకొస్తున్నాడు.

'వాళ్ళ దయా దాక్షిణ్యాల వల్లే మనమింకా శవాలుగానైనా బతగ్గలుగుతున్నాం.. కాబట్టి వాళ్ళ కవసరమనిపిస్తే మన తల్లుల్ని పెళ్ళాల్ని, పుట్టిన, పుట్టబోయే జనాభానంతా తాకట్టు పెట్టెయ్యగలరు కాబట్టి – మనం కుష్ఠ దేవుళ్ళ గొప్పదనము చాటాలి.. అని ఈ దేశ ఆర్థిక పరిస్థితిని సూచిస్తున్నారీ కవులు. రాజకీయ నాయకులు పాలక వర్గ ప్రయోజనం కోసం ఎంత నీచానికైనా దిగజారడానికి సిద్ధంగా ఉన్నారు.

మానసికంగా ఎదగనీయని సినిమాలు, పత్రికలు, రాజకీయాలు, సాహిత్య సంస్థలు, విశ్వవిద్యాలయాలు అన్నీ వేటికవే కలుషితం అయ్యాయి. సమాజమంతా గమ్యరహితంగా నడుస్తున్నది. గమనాన్ని నిర్దేశించాలని వీరి కవిత్వ తపన.

> 'ఏ కులమఖ్ఖీ
> మాదే మతమఖ్ఖీ
> మట్టి పిసికి ఇటుక చేసి
> ఇల్లు కట్టి పెట్టినపుడు..
> డొక్కలెండి కొండ్రా చేసి
> ధాన్య రాసులెత్తినపుడు..'

అంటూ మాహ్లోద్రేకంతో చెరబండరాజు రాసిన కవిత్వ పంక్తులు అగ్రకులాల వాళ్ళకు చెంపపెట్టులా సాగాయి. పాటలా

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సాగిన ఈ కవిత్వం ఎంతో మందిని కదిలించి, ఆలోచింప చేసింది. కర్షక, శ్రామిక ప్రజలు లేకపోతే మానవ మనుగడ లేదు. కుల మత నిర్మూలనే కాదు.. పురుషాధిక్యతను కూడా చీల్చి చెండాడాలని చెరబండ రాజు అన్నారు.

> "మీ రాత్రి చొక్కాలు పగళ్ళు నిలువవు
>
> పగటి చొక్కాలు రాత్రి వుండవు
>
> మీ పెళ్ళాలు పిచ్చివాళ్ళు
>
> పాత చీరతో స్వర్గాన్ని కప్పుకొని
>
> వంట గదిలో ఆలోచనలకు
>
> ఎసర్లు పెడుతున్న వాళ్ళు
>
> మీ వాగ్దానాలు పుచ్చు గింజలు
>
> మీ బిడ్డలు కృత్రిమ నాగరికత షోలో
>
> మోడల్ గా పనికొస్తున్న వాళ్ళు.."

అని ఎలుగెత్తి నినదించిన కవులు దిగంబర కవులు. వీరు ఏ రచన చేసినా భావ వ్యక్తీకరణ, వారి వాక్ప్రవాహం కొంచెం కఠినంగా ఉన్నా ఇప్పటి సమాజానికి కూడా నిత్యనూతనంగా ఉండడం గమనించదగిన విషయం! ఒకానొక సందర్భంలో మహాకవి శ్రీశ్రీ మాట్లాడుతూ, "అభ్యుదయ కవిత్వం ఆంధ్రదేశంలో తన పాత్ర నిర్వహించి తెర వెనక్కి తప్పుకుంది. ఇప్పుడు కొత్త శక్తులు పెరుగుతున్నాయి.

కొత్త మంటలు రగులుతున్నాయి. అభ్యుదయ కవిత్వం ఒక వెంటెడ్ ఇంట్రెస్ట్ కాకూడదు. ఇవాళ రాస్తున్న వాళ్ళలో దిగంబర కవులు, తిరుగుబాటు కవులు, సంఘర్షణ కవులు వచ్చారు. చేతనైతే వాళ్ళకి చేయూత నివ్వండి.. లేకపోతే నోరు ముయ్యండి.." అని గట్టిగా మందలించి దిగంబర కవిత్వాన్ని సమర్థించాడు!

ఉపయుక్త గ్రంథ సూచిక

1. ఆధునిక తెలుగు కవిత్వంలో– విప్లవధోరణులు– ఒక విశ్లేషణ – డాక్టర్ మంచాల గంగాధర్

2. ఆధునికాంధ్ర కవితా సమీక్ష – ఆచార్య. కాకర్ల వెంకట రామ నరసింహం.

3. దిగంబర సాహిత్యం – వికీపీడియా.

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Unveiling the competitive advantages of MSM-sized enterprises: A Study on HRD & Information Technology practices in Engineering

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Abstract:

In this study, we discuss several programs that aim to increase human resource skills for the sake of the sustained success of management in small and medium-sized businesses (SME). In order to provide a response to this question, we gathered a wide variety of facts and information from a wide variety of written sources and presented it in the form of scientific studies. We investigated many publications and online resources that offered scholarly information on micro, small, and medium businesses (MSMEs) as well as human resources. Our review was carried out by encoding the data, evaluating it, and drawing pertinent conclusions to answer the problem based on the study, reporting, and discussion. Through this process, we discovered that strong managerial will was required for efforts to increase human resources for digital-based MHM managers in order for those efforts to be profitable and sustainable. MSMEs to develop initiatives that, if successful, would enhance the total amount of money that is available to MSMEs. Because of this, the use of language that is upbeat and positive in regard to this finding is a crucial one..

Keywords: MSMEs, SMEs, Human resource

INTRODUCTION:

Small and medium-sized firms, commonly referred to as SMEs, make a substantial contribution to the expansion of economic employment and the development of economies all over the world. This is especially true in developing countries. Small and medium-sized businesses (also known as SMEs) make up around 90 percent of all businesses and employ more than half of the working population across the globe. Small and medium-sized firms (also known as SMEs) are responsible for up to forty percent of the gross domestic product (GDP) in countries that are still in the process of developing. When informal small and medium-sized enterprises (SMEs) are taken into account, the estimations reflect a significant growth, as stated by the World Bank (2017). According to forecasts made by the World Bank, there will be a need for an extra 600 million jobs by the year 2030. This need will be driven by an increasing global workforce. As a direct consequence of this, the growth of small and medium-sized businesses has emerged as a top priority for a significant number of countries all over the world. In developing nations, small and medium-sized businesses (also known as SMEs) are the principal generators of organized employment. In these countries, SMEs are responsible for seven out of every 10 workers, making up 70 percent of the overall workforce. Access to capital, on the other hand, is a major obstacle to the expansion of small and medium-sized businesses (also known as SMEs), and it is the second most widely cited

barrier to the expansion of SMEs in both established and emerging markets (Kumar R., 2017). The much-anticipated SMI system in Telangana has been a major component of the state's strong push for industrialization. This push was initiated by Telangana..

Small and Medium-sized Manufacturing Engineering Enterprises (SMMEEs)

A concentrated effort to support the expansion of small businesses is one of the many initiatives that the government of Telangana has made to jumpstart the expansion of the economy of the state. This program is one of the most significant of the many initiatives that the government has announced. The creation of new infrastructure, the diversification of existing industries, and the growth of existing output have all made significant strides forward. The emergence of small and medium-sized businesses has injected the economy of the state with a new lease on life and given it a renewed sense of vibrancy. It is believed that there are fifty million micro-companies doing unorganized operations in the state of Tamil Nadu. These enterprises have not been registered with the state government. According to information obtained from Udyog Aadhar, the total number of micro, small, and medium- sized companies in the state is 7.7 lakh. Manufacturing, aerospace, automotive, agricultural, culinary, information technology, and biotechnology are just few of the numerous areas in which small and medium-sized firms are active participants. Businesses are always searching for new ways to enhance the efficacy and productivity of their operations as a direct response to the intensifying global competition and the increasingly unstable state of the economy. Measuring the sustainability of a company's operations has emerged as a major topic of conversation in both the business world and the academic world. This is due to the fact that companies are constantly looking for methods to improve their effectiveness and efficiency. In order for enterprises to accomplish this goal, they need to rely on the selection of sustainability indicators. This is made possible by the utilization of sustainability management models, which assure alignment with business policy. These assessment methods, on the other hand, almost never include specifics on the criteria for sustainable development that are presently being used or the indicators that are now being made available. An accurate evaluation of the company's ability to continue operations despite the challenges presented by the current environment would be beneficial to the company, its creditors, and its investors. It is possible to examine both internal and external possibilities and threats with this evaluation, which is one of the most important tools available. After reading this, there are certain companies that might benefit from having a better understanding of where they stand in comparison to other companies.

In this study, the AHP was applied in an effort to assess whether or not Indian SMMEEs, which stands for small and medium-sized manufacturing engineering firms, had a chance of succeeding. The study also found global priority weighted indicators of the viable and competitive business environment for manufacturing engineering companies in India. India is a nation that possesses a sizable pool of human resources, and in the present environment, the development of SMMEEs is the most significant and realistic choice for achieving open and sustainable growth in India. It is possible that one day, people in the rural sections of the state may be able to find well-paying job that will set them on the path to becoming financially independent, regardless of their level of qualification or experience. This is due to the fact that SMMEEs have just recently arisen and have seen tremendous proliferation. Because of

this, fewer people who live in rural areas who are currently without jobs will feel driven to leave their towns in order to look for employment elsewhere.

Micro, Small and Medium-Sized Enterprises in India

The growth of India's economy is expected to remain consistent throughout the course of the next several years, according to various forecasts. The manufacturing sector of India's economy is an essential and foundational component of the country's overall economy. Because it generates such a large number of employment, not only does India's GDP profit immensely from it, but so do the people of that country. After China, India has the second- highest concentration of micro, small, and medium-sized enterprises (MSMEs; firms with less than 500 employees) in the world. Micro, small, and medium-sized businesses (often abbreviated as MSMEs) are responsible for the production and delivery of thousands of different goods and services. In India, the definition of a micro, small, or medium firm has been expanded to include consideration of investment and income. Under the amended definition that was released on May 13, 2020, Micro, Small, and Medium-Sized Businesses (MSMEs) in India will be included. MSMEs in India comprise both manufacturers and service providers, and the revised definition will apply to both types of businesses. Manufacturing enterprises are businesses that "manufacture" or "produce goods relating to any industry specified in the first schedule to the Industries (Development and Regulation Act of 1951) or use plant and machinery in the process of value addition to the final product having a distinct name, character, or use. In India, manufacturing enterprises are defined as businesses that "manufacture" or "produce goods relating to any industry specified in the first schedule to the Act. The degree to which the firm has invested in its machines and tools is one of the most telling indicators that it is a manufacturer. "Services companies" are businesses that "provide or render services defined in equipment investment" in India. This definition of "services company" The service industry in India employs about 50 million people, which makes it the most important economic sector in the country. This sector accounts for over half of India's total labor force.

However, the manufacturing industry was only able to meet fifty percent of its objectives. In India, the value of fixed assets held by small companies was over two trillion Indian rupees, proving that the adage "small things make the largest impact" is applicable to micro, small, and medium-sized enterprises (MSMEs). "The majority of employment is provided by unregistered businesses," and "the reluctance and avoidance of the challenging registration process is quite evident." Micro, small, and medium-sized enterprises (also known as MSMEs) in the country have a tremendous potential for expansion provided the government provides them with assistance, allows them to have a greater say in the development of infrastructure, and streamlines the registration process. (Statista Research Department, 2020).

- According to India Briefing (2020), the new definition expands the scope of commercial companies that are now entitled to make use of their MSME classification and the benefits that come along with it. Specifically, the new definition makes it possible for more businesses to benefit from their MSME classification. Included on the list are examples of each of the following types of companies:

- Small-sized firms are defined as businesses with an investment of up to US$1.3 million and an income of up to US$6.62 million. Middle-sized firms are defined as

businesses with an investment of up to US$2.6 million and an income of up to US$13.24 million.

HUMAN RESOURCES DEVELOPMENT (HRD)

It is believed that Professor Leonard Nadler of George Washington University was the first person to use the word "Human Resources Development" (HRD) in a scientific setting in the year 1968. It is generally acknowledged that he was the first person to use the term "learning organization" in a formal setting, and that he did so in 1969 at a conference hosted by the American Society for Training and Development. At initially, there was a lot of skepticism directed against the term among those working in business and management. However, beginning in the middle of the 1970s, there was a discernible rise in the importance of the concept. As a direct consequence of this, the phrase "human resource development" and its associated connotation came into being. The purpose of human resource development, often known as HRD, is to provide workers with the support necessary to help them make the most of the skills, knowledge, and talents they already possess inside their company. HRD, which stands for "human resource development," is the process by which a company assists its workers in acquiring the knowledge and abilities that will allow them to make a positive contribution to the firm's performance both now and in the future. People, often known as "Human Resources," are a nation's most important and valuable asset. This is true regardless of whether we are discussing the United States of America, Japan, or India. Increases in human capital have been the focus of a significant amount of study and are now widely acknowledged as a crucial component of economic development across the board in every part of the world. In industrialized nations, the contribution of physical infrastructure and other aspects of infrastructure to economic growth is much smaller than in developing countries. There has been a significant increase in the number of individuals who are aware of the fact that people are the primary factor in the expansion of any culture's economy. Findings from study and practical experience in the field of social sciences point to the possibility that the contributions of physical capital alone may no longer be considered to be the determining ingredient in the expansion of any human civilization.

HRD Philosophy

The concept known as human resource development (HRD) proposes that the executive management of a firm should strive to make the working environment a good and healthy one so that its employees may develop both professionally and personally. This ensures that employees will put out their greatest efforts to contribute to the expansion and success of the organization. In the long run, human resource development (HRD) programs that have a philosophical viewpoint tend to generate workers who are happier; these are the individuals who are most involved in both their own personal growth and the success of the firm. The human resource development (HRD) philosophical perspective states that:

Procedure of Human Resource Development

The attempts at human resource development (HRD) made by a great number of businesses are unsuccessful mainly because the required processes, most notably the frameworks, are ignored. That is one of the primary contributors to the overall failure. The concept of a process is primarily focused on the "how," and to a certain extent, the "why." The metrics that focus on behavior and interaction are given a higher priority. Every HRD model concentrates

on different parts of an organization, such as the individual worker, the department, the group working together, and the business as a whole. In the absence of appropriate attention, the one-of-a-kind regulations and processes that are specific to each department have the potential to undermine any efforts made to realize the organization's objectives. These processes are absolutely necessary for the successful execution of HRD frameworks inside enterprises. As a result, it is essential to recognize 12 different HRD frameworks' executions in order to create optimal processes in enterprises. Models for developing human resources and methods for developing human resources are now linked. Someone who is considered indispensable to the accomplishment of the goals of a group. Human beings are the source of all social rules as well as all of the feelings that we experience. The individual-based HRD methods that will be detailed here are extremely important to the success of human resource development (HRD) activities as well as the implementation of HRD frameworks.

HRD in Indian industry

Before the 1970s, human resource development (HRD) may have been practiced in India, but it wasn't until after that decade that it was approached with any kind of seriousness. It is possible that Larsen and Toubro was the first Indian business in the 1970s to design and put into action an all-encompassing strategy for the purpose of enhancing its human resources. After a period of time, a number of companies began to use this well-informed approach for HRD in their operations. 1979 was the year that saw the first major HRD conference. Since that time, there have been more lectures and training sessions. The Xavier Labor Relation Institute (XLRI), which is located in Jamshedpur, is the central location for HRD activities. Another era of expansion for National HRD Network occurred in the year 1985. Human resource development (HRD) departments and HRD supervisors are found in just a select few open and private sector businesses in today's business landscape. In the year 1982, T.V. Rao directed a survey that was conducted to investigate the practices of human resource development (HRD) in Indian enterprises. According to the findings of the study, there is an increasing tendency toward the adoption of open evaluation frameworks, the enhancement of preparation work, the acceptance of association development, and the usage of worker advising. Despite this, there were not going to be any big modifications in the future assessment and promotion, compensation structure, or promotion alternatives that were taken into account. The survey included 53 different companies, but just 17 of them had any kind of organized HRD strategy. After going through all of the data and analyzing it, it seemed that HRD was becoming an increasingly significant element of the day-to-day operations of many different types of businesses. One of the focuses of a distinct piece of study was on the HRD culture prevalent in Indian enterprises. According to the findings of the study, the environment as a whole did not lend itself well to human resource development (HRD). This was primarily because the representatives showed a general lack of interest in their own personal development. Even the most effective management in many businesses was not doing enough to improve the working conditions of their employees to the point where they were satisfied with their lives overall. The progression of HR policies and practices is currently the focus of a significant amount of attention at the strategic level. The previous Ministry of Human Resource Development is now operating as an independent department after being spun off by the federal government. In the United States, one of the most important goals is to integrate non-formal and formal learning, as well as health and adult

education, with other types of social programs. The current tidal wave of technological and logical advancements is becoming an increasingly important factor in the development of HR. If qualified HR personnel are not easily available to employ the physical assets, then such assets are of poor value.

The effect of putting money into the development of human resources

The growth of human resources has an effect since people make the fundamental decision to arrange the dynamic elements related with every contact. This is a fact about every nation, as it is the residents of that nation who determine the acceptable degree of consumption for each additional supply. How far a group progresses is directly proportional to how well they are able to "push" or "drag" other groups along with them. This indicates the degree to which the association is able to exert a push in the direction of advancement and the degree to which it is able to endure a drag that leads it to change its direction of travel. Given all of the things it is capable of doing and the different outcomes it may provide, human resources is frequently identified as an essential component in collaborative efforts to define, align with, and enhance the push effort itself. This is not hard to understand. In addition to that, measures for the development of human resources has to be included because: It is beneficial for developing the all-around development of specialists. Because they are aware of both their capabilities and their limitations, experts are able to improve both themselves and the organizations in which they work.

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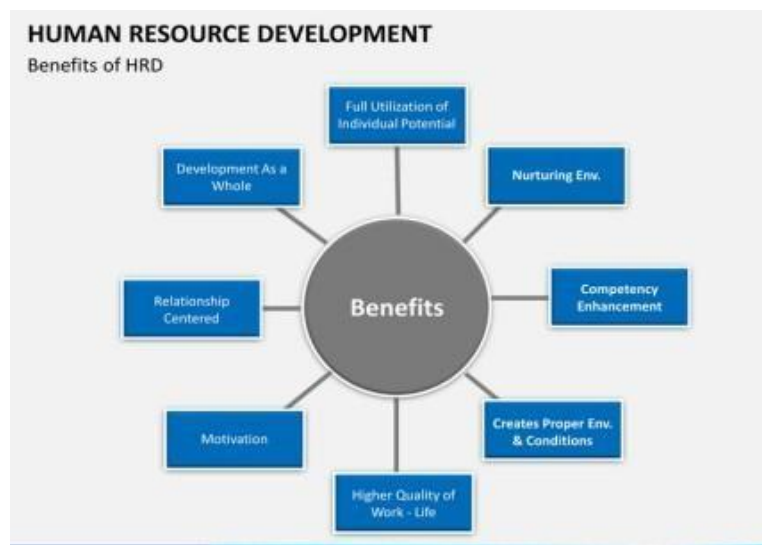
Figure 1.1

The HRD process is mostly focused on people. Every single association is made up of people, materials, machines, and/or frameworks, and among the vast majority of every one of these components, individuals are of a special classification. This isn't only on account of the fact that individuals have their own particular needs, thoughts, feelings, convictions, and yearnings, yet additionally on account of the fact that individuals are the prime movers behind other components. "Individuals are the association's human assets and are consequently important to the organization.".

REVIEW LITERATURE:

The authors Khan and Khan (2021) make an attempt to provide a literature study on the subject of "A hierarchical idea of HRD and how Human Resource Management."

Researchers in the field of administration consider HRD to be a sub-teaching of HRM. Academics concentrate their studies on HRD since they consider it to be an essential component of the situations that exist nowadays. Researchers in administration typically consider HRD to be a sub-teach of HRM. Preparing, training, and the development of expertise are all examples of notions that they consider to be within the umbrella of HRD. In addition to these operations, it also comprises actions such as sharpening and business development, human resource arranging and arrangements, group building, awareness raising, authoritative advancement, network activation and advancement, and strengthening. Samuel (2019) conducts research on the impact that the execution assessment system has had on the staff execution in Ghanaian academic libraries. This research can be found in Samuel (2019). It is vital to do an execution review in order to get inspiration, to aid with picking the participation of employees, and to guarantee that they will generate work that is sustainable. This is because the member is responsible for carrying out the task. The results of the study suggested that attention should be given to the execution assessment framework in academic libraries by means of inspiration, clarity of the rating criteria, via preparation of appraisers, examination meeting or counseling, and recurrence of evaluations. This recommendation was made as a result of the findings of the study. As a consequence of the results of the examination, this was recommended to be done.

Kanade and Deshmukh's (2019) essay is on the subject of "In this age of computerization, why consistent preparation and updates in learning about trend setting innovation are vital for library staff," which is the topic that the focus of the study focuses on. Training of workers is vital not only because it ensures that available labor is used in an effective manner, but also because it helps an organization achieve the goals it has set for itself and maintains a high morale among its employees. Training of workers is essential not only because it ensures that available labor is used in an efficient manner, but also because it guarantees that available labor is utilized in an efficient manner. According to the findings of the study, there are a few key components that should be prioritized in order to significantly improve the quality of library services. These include total quality management, human resource development, human resource auditing, and human resource research. The library staff will be motivated to perform at a level that is suitable for the company by participating in the HRD program, which teaches a range of skills.

Kumbargoudar's (2019) study was to evaluate the amount of ICT competency had by library professionals working in the academic libraries of degree schools and college libraries located in the city of Gulbarga. Specifically, the researchers were interested in determining the level of ICT competency possessed by library professionals. The findings of the study suggest that preparation programs have to be designed for degree institutions due to the fact that while library staff members are knowledgeable in traditional aspects of librarianship, they are not aware with the evolution of information and communication technology or its various uses. It would appear that the instructors and staff at the institution have a considerable amount of knowledge in this area. As a result of the investigation, it was suggested that the specialists working in the library at the university should be in charge of directing the programs of preparation and introduction that are designed for the school curators and various other specialists who are engaged in the city of Gulbarga.

OBJECTIVE OF THE STUDY

1. To study the component that affects both the quality of HRD and the results of workers' awareness
2. To study on those businesses that fall into the categories of micro, small, and medium size in India
3. To study the effect that HRD& information technology procedures have on staff members.

RESEARCH METHODOLOGY:

Both primary and secondary sources of information were looked at as part of this research endeavor so that its objectives might be met. The original data came from the employees of the company, who were interviewed for it. This information was acquired from them. In order to achieve this objective, a comprehensive questionnaire was designed, and responses from workers were gathered about a wide range of issues. These responses were obtained from employees regarding socio-economic conditions, the present state of their jobs, and HRD procedures, among other things. In order to get some of the relevant information that was acquired, interviews were conducted with the staff and leaders of SCCL in the kothagudem Area. The secondary data were gathered from a wide variety of sources including books, periodicals, and the internet. Only those who worked for SCCL in the Kothagudem Area could take part in the research, hence the pool of potential participants was somewhat small. In order to meet the requirements of this study, a representative sample of about one hundred twenty staff members was selected at random. The sample has representation from a wide variety of staff employees holding a number of different positions. This sample includes individuals from a variety of different ranks and departments, including Officers (15), Clerks (22), Technicians (Diploma holders) (18), Supervisors (12), General Mazdur (16), and Labor
(37).

Competitive Advantages:

- Cost Efficiency: How HR and IT practices help MSMs reduce operational costs and compete with larger firms.
- Innovation: How MSMs leverage HR (e.g., fostering a culture of innovation) and IT (e.g., using design and prototyping tools) to develop new products and services.
- Agility: How HR practices (e.g., flexible work arrangements) and IT (e.g., cloud- based solutions) enable MSMs to adapt to changing market demands quickly.
- Customer Focus: How HR practices (e.g., customer service training) and IT (e.g., CRM systems) help MSMs provide exceptional customer service and build strong customer relationships.

HRD Practices:

- Talent Acquisition & Management: How MSMs attract, retain, and develop skilled employees in a competitive talent market. This could involve examining their recruitment strategies, training programs, and performance management systems.
- Work Culture & Employee Engagement: How MSMs create a positive and engaging work environment to boost employee morale and productivity. This could involve looking at their leadership styles, communication practices, and employee recognition programs.

Information Technology Practices:

- IT Infrastructure & Adoption: How MSMs leverage technology to streamline operations, improve communication, and enhance collaboration. This could involve examining their IT infrastructure (hardware, software), and their adoption of digital tools (e.g., project management software, communication platforms).
- Data Management & Analytics: How MSMs use data to gain insights into their operations, customers, and market trends. This could involve their data collection practices, data analysis capabilities, and how they use data to inform decision-making.

For further research:

- You can conduct interviews or surveys with HR managers, IT professionals, and engineering professionals in MSM enterprises in Hyderabad and Secunderabad.
- Case studies of successful MSM engineering firms in the twin cities could provide valuable insights into their HR and IT practices.
- Government initiatives or industry reports related to HRD and IT adoption in MSM enterprises in India might be helpful.

By examining these areas, your study can contribute valuable knowledge to the field of business management, particularly for MSM enterprises in the engineering sector

DATA ANALYSIS:

Potential capacity optimization is a topic that receives a lot of attention in settings where human resources are considered to be an essential component of growth or development. The process of growth is not predetermined or mechanistic in any way. As is the case with every endeavor involving humans, the aptitude, nature, and level of motivation of the people involved will determine whether or not the endeavor is successful. In light of the sample's responses to questions about pay, training, recognition of work, appraisal, promotion, welfare, medical facilities, day-to-day problems, quality of physical conditions, compensation, union and management relations, and training, human resource development (HRD) practices were thoroughly examined. These practices include those used by SCCL in the kothagudem area. The following is the breakdown of each one:

.Table 1: Age Particulars of Respondents

S.No	Age	No. of Respondents	Percentage
1	25-30	24	20
2	31-40	45	36.5
3	40 and above	51	41.5
	Total	120	100

Source: Primary data

According to the data presented in the table, the age group consisting of respondents aged 40 and over accounts for 42.5 percent of the total. Adults between the ages of 31 and 40 make up the second largest group, accounting for 37.5% of the total population. About twenty percent of the overall population falls into the youngest age bracket, which consists of those aged 25 to 30 years old. Young people made up the great majority of individuals who responded to the

survey. Younger employees frequently outperform their more experienced colleagues because they are willing to put in longer and more strenuous hours to achieve the same goals.

Table 2: Educational Qualifications of Respondents

S. No.	Educational Qualifications	No. of Respondents	Percentage
1	Non Matriculate	15	11.50
2	High School	23	19.16
3	Diploma	17	13.14
4	Degree	27	21.50
5	Post-Graduation	08	05.66
6	No Education	30	24.00
	Total	120	100.00

Source: Primary data

When looking at the results of the survey, it is clear that over a quarter of the people who participated are illiterate. One in every twelve and a half percent of those questioned did not complete high school. In the sample, there were a greater number of individuals who had degrees as compared to those who held diplomas (22.5 to 14.16 percent), although only a small percentage of individuals (6.67 percent) held postgraduate degrees. The amount of education that is necessary for a job opportunity is established by the characteristics of the occupation. Due to the fact that the majority of the sample is employed in low-level manual labor, which does not require advanced degrees, the chart makes it abundantly clear that the majority of the sample does not possess advanced degrees. This is due to the fact that the work they conduct does not require a higher degree of education to do. However, the figures also show that a sizeable percentage of workers have received degrees or certificates in subject areas that are pertinent to their jobs.

Experience in business is extremely useful since it reduces the amount of time needed to learn new things and boosts overall productivity. People who have experience working in a certain industry for a longer period of time are more prepared to handle the obstacles and meet the demands of their employment than individuals who are just beginning their careers in that industry.

Table 3: Experience of the Respondents

S.No	Experience of Respondents	No. of Respondents	Percentage
1	5-10 years	30	25
2	10-15 years	38	30.5
3	15 and above years	52	42.3
	Total	120	100

Source: Primary data

The information shown in the table that comes before this one makes it plainly clear that a sizeable portion of the sample had professional experience that was greater than 15 years. The next largest group had between 10 and 15 years of experience, accounting for 31.60 percent of the total, and this group made up 43.40 percent of the total. In conclusion, 25% of the total is comprised of responders who have between five and ten years of experience.

Methodology:

The study could employ a mixed-method approach, combining quantitative and qualitative data collection methods. Here's a possible approach:

- **Quantitative data:** Surveys can be conducted among MSM engineering enterprises to gather information on their HRD and IT practices, employee skillsets, and performance metrics.
- **Qualitative data:** Case studies can be conducted on successful MSM engineering enterprises to gain deeper insights into their specific HRD and IT strategies and their impact on competitive advantage. Interviews with key personnel can also be conducted to understand their experiences and perspectives.

Expected Outcomes:

The study is expected to identify best practices in HRD and IT for MSM engineering enterprises. It will also provide insights into how these practices can be leveraged to achieve:

- A more skilled and engaged workforce
- Improved efficiency and productivity
- Enhanced innovation capabilities
- Stronger competitive advantage

Table 4: Income Levels of Respondents

S.No	Income range	No. of Respondents	Percentage
1	Less than 10,000	0	00.00
2	10,000 – 20,000	87	71.50
3	20,000- 30,000	22	17.32
4	30,000 above	11	08.15
	Total	120	100

Source: Primary data

Quite a number of those who filled out the survey Seventy percent of employees responded to a recent poll that they are either extremely happy or satisfied with the benefits and income that they receive from their workplace. Although just a very small percentage of individuals were unhappy with it, 25 percent of people continue to grumble about it. There is not the slightest shred of uncertainty in anyone's mind regarding the fact that the SCCL offered very considerable compensation to its staff members. When wage talks took place at SCCL, a significant amount of weight was given to the strength of employees' links to the union.

Training, no matter how comprehensive or brief, gives an individual the structure and direction that are need to maintain a lifetime dedication to learning. In general, the training techniques that are used to fulfill particular standards should be designed to spark the attention of the participants, demonstrate the essential abilities, and promote active engagement from the trainees.

Table 5: Training Methods and Procedures

S. No	Response of the Respondents	No. of Respondents	Percentage
1	Highly Satisfied	21	16.40

2	Satisfied	93	76.40
3	Dissatisfied	03	01.40
4	Highly dissatisfied	00	00.00
5	Silent	03	01.40
	Total	120	100.00

Source: Primary data

According to Table 5, a whopping 95% of respondents are either in agreement or strongly agree that their organizations make use of efficient training techniques. In spite of this, there is a teeny-tiny minority of responders that are either unsatisfied with the question or choose not to reply at all. The vast majority of responders indicate that they were content with the various training strategies that were presented to them at SCCL. This is evidence that training has been provided to all different kinds of workers in order to improve their abilities and greatly raise output.

Table 6: Development of Skills of Less Skilled Personnel

S. No.	Response of the Respondents	No of Respondents	Percentage
1	Highly Satisfied	21	16.40
2	Satisfied	61	40.73
3	Dissatisfied	08	05.57
4	Highly Dissatisfied	18	14.00
5	Silent	12	10.00
	Total	120	100.00

Source: Primary data

It is abundantly obvious from the table that the vast majority of respondents are pleased with the actions taken by the organization for the advancement of the workers with lower levels of expertise. About 68.33 percent of those who responded are either content or very satisfied with the measures, whereas 31.67 percent of those who responded are either unsatisfied or very dissatisfied with the measures, or they remained silent.

The workers who lacked skills or had only a partial skill set benefited greatly from the training programs that were offered. The SCCL kothagudem Area has launched a variety of specialized training programs for workers who are unskilled or only have a moderate degree of expertise in order to raise their overall levels of productivity.

.**Table 7: Self Employment Training to Family**

S. No.	Response of the Respondents	No of Respondents	Percentage
1	Highly Satisfied	24	20.00
2	Satisfied	66	54.00
3	Dissatisfied	06	04.00
4	Highly Dissatisfied	15	11.40
5	Silent	09	06.40
	Total	120	100.00

Source: Primary data

The pie chart demonstrates that seventy-five percent of respondents are pleased with the training programs that the organization developed to assist family members in locating

opportunities for self-employment. Twenty-five percent of those who took the survey either have mixed feelings, are upset, or are hesitant to provide their view.

It is common knowledge that financial gain is not the only factor that may inspire individuals. People go to work with the expectation that they will be respected as workers, that they will receive positive comments on their performance, and that they will make friends while they are there. In acknowledgement of outstanding performance, one may get non-monetary prizes such as letters of gratitude, certificates of achievement, medals, and other items of a similar nature.

Table 8: Recognition of Work

S. No.	Response of the Respondents	No of Respondents	Percentage
1	Highly Satisfied	15	11.40
2	Satisfied	66	54.00
3	Dissatisfied	27	21.40
4	Highly Dissatisfied	10	07.20
5	Silent	02	01.60
	Total	120	100.00

Source: Primary data

A majority 67.50 percent of the respondents revealed that their work was recognized duly by authority, and in addition to that, they were given monetary incentives, non-monetary incentives, and prizes in appreciation of their abilities and individual achievements in their respective fields of employment. This was done in recognition of the fact that they had excelled in those fields. About 30.80 percentage of individuals who replied expressed their dissatisfaction with the fact that they were not reimbursed adequately for the services that they supplied.

An evaluation will take into account not just how well a person performs his or her current duties but also how much room there is for that individual to expand and improve in the future. The assessment system bolsters the employees' belief that effort will lead to acceptable performance, and satisfactory performance is what finally leads to rewards and prizes for the staff. The employees' trust in the effort leading to adequate performance is what ultimately leads to the rewards and prizes..

Table 9: Appraisal System in Company

S. No.	Response of the Respondents	No of Respondents	Percentage
1	Highly Satisfied	20	15.57
2	Satisfied	50	40.57
3	Dissatisfied	36	30.00
4	Highly Dissatisfied	05	03.16
5	Silent	09	06.40
	Total	120	100.00

Source: Primary data

According to the findings, about 58.34% of the general public are content with the present methods of evaluation that are being carried out by the organization. A total of around 34.16 percent of the sample's respondents have expressed either dissatisfaction with the evaluation technique or extreme dissatisfaction with it. On the other hand, 7.50 percent of respondents

did not provide any response at all in response to the question and remained silent for the entirety of the procedure.

When a person is given a promotion, they move into a position that is better for them than the one they previously had in terms of compensation, prestige, prospects for advancement, and any number of other variables that may be considered. In other words, the individual's standing is improved as a result of the promotion in some fashion.

Table 10: Promotion Policy of the Company

S. No.	Response of the Respondents	No of Respondents	Percentage
1	Highly Satisfied	12	10.00
2	Satisfied	56	45.57
3	Dissatisfied	30	24.00
4	Highly Dissatisfied	13	10.73
5	Silent	09	06.40
	Total	120	100.00

Source: Primary Data

The information shown in the table above allows us to draw the conclusion that 46.67 percent of respondents are pleased with the promotion program that the firm offers, while 10% are absolutely ecstatic about it. The results in the table above show that twenty-five percent of respondents are dissatisfied with the promotion program that the firm offers, while seven point five percent of respondents did not provide an answer.

When welfare measures are put into effect, they assist individuals in living better lives overall by providing them with greater stability and prestige in their place of employment. When employees are provided with welfare measures, whether official or informal, they have a greater sense that they belong in their place of employment. Their presence has a positive effect on the production of the workers as well as on their morale.

Table 11: Welfare Measures in Company

S. No.	Response of the Respondents	No. of Respondents	Percentage
1	Highly Satisfied	18	14.00
2	Satisfied	66	54.00
3	Highly Dissatisfied	-	-
4	Dissatisfied	30	24.00
5	Silent	06	04.00
	Total	120	100.00

Source: Primary Data

The table makes it clearly clear that the majority of the respondents are content with the level of care exhibited by the organization for the employees and with the company's execution of welfare measures to safeguard the employees' wellbeing. This conclusion can be drawn from the fact that the majority of the respondents have expressed satisfaction with both aspects. It is possible to label around seventieth of individuals who took part in the poll as either pleased or highly satisfied with their experience. A minimum of thirty percent of those who responded to the survey did not offer an opinion or chose to keep silent about the issue.

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Table 12: Union and Management Relations

S.No	Response of the Respondents	No. of Respondents	Percentage
1	Highly Satisfied	21	16.40
2	Satisfied	31	24.63
3	Dissatisfied	15	11.40
4	Highly Dissatisfied	08	05.57
5	Silent	45	36.40
	Total	120	100.00

Source: Primary Data

It's possible that the figures in the table above indicate an overwhelming majority. The proportion of respondents who reported being extremely pleased and those who reported being satisfied with the working relationship between the union and management was almost equal. In addition, 37.50 percent of those who were interviewed did not find the topic important enough to comment on, and 19.17 percent were unhappy or extremely dissatisfied with the method in which Union-Management relations were managed.

One of the most important things that a company possesses is its workforce. The cultivation of human resources is an excellent plan. Human resource development strategies not only bring about a more pleasant working environment for employees but also ensure that businesses remain current on the latest management trends. This helps to ensure that human resources are completely incorporated into the daily operations of the organization. Because of this, the workforce has a greater emotional investment in the company's overall success.

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Table 13 : HRD Practices of SCCL

S. No.	Response of the Respondents	No. of Respondents	Percentage
1	Highly Satisfied	50	40.57
2	Satisfied	44	35.57
3	Dissatisfied	05	03.16
4	Highly Dissatisfied	15	11.40
5	Silent	06	04.00
	Total	120	100.00

Source: Primary data

A majority The overwhelming majority of respondents (78.34 percent) are satisfied with the HRD Practices that are made available in the organization. The amount of people who are either unhappy with the response or choose not to comment on it is extremely low. The remaining 12.50 percent of survey takers are very dissatisfied with the service.

It is easy to observe that the majority of respondents had a positive assessment of the HRD practices that SCCL has put into place. On the other side, they discussed how joyful they were and opened up to the researcher about their feelings. In point of fact, HRD practices make it simpler for employers to contribute to the expansion of their firms, which in turn benefits everyone involved.

CONCLUSION:

In this last section, we will summarize the findings that we obtained from the evaluation of the relevant literature, and then draw some conclusions regarding the primary topics that we have covered. We will also underline the importance of the necessity of making an attempt to expand the number of highly trained human resources that are accessible to the management of MSMEs in order for such businesses to have increased future financial success and viability. According to the findings of our research, technologically-based human resource management has been the primary reason for the management of micro, little, and medium- sized businesses (MSME) in some geographic locations. This has led to the conduct of scientific field studies in these geographic areas. The staff members who are in charge of managing micro, small, and medium-sized firms (also known as MSMEs) have earned the proper training and qualifications to do so. Because having access to these individuals is the single most important factor that determines whether or not a company is successful in its sector, regardless of the company's area of specialty. Okay, so after some consideration, we've come to the conclusion that the administration of human resources for small and medium- sized businesses (SMEs) is beyond our skills. since of this, we have a strong human resources department since we concentrate on aspects that are essential to the department's expansion, such as the manager's recruitment procedures. Next, the people of the MSME, also known as its human resources, need to be adequately trained. As part of this process, there should be some wiggle room regarding the selection of the religious tenets. In a similar manner, micro, small, and medium-sized firms (often abbreviated as MSMEs) have to have a framework in place for the development of MSMEs operating standards, such as functioning in line with such standards.

Further Research:

This study can be a springboard for further research exploring specific HRD and IT practices within different engineering sub-disciplines. Additionally, the impact of these practices on specific aspects of competitive advantage, like cost reduction or market access, could be investigated.

By delving into HRD and IT practices, this study aims to unveil the hidden strengths of MSM engineering enterprises and empower them to thrive in the competitive landscape.

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A study on "Customer's satisfaction level and the influencing factors towards Green Products"

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Abstract

"Being green is more than just buying eco. It is an unshakable commitment to a sustainable lifestyle." Green Products have less effect on the environment, creating a rapidly growing shift towards going green and purchasing green products. In this specific circumstance, green products are becoming a vital component in progress to sustainable consumption of the environment. This research has been endowed with additional information in narrowing the research gap about understanding consumers' green awareness befitting the role of consciousness enhancing consumers' changing attitudes and perception levels towards green products and their green purchasing behaviour. This paper is an exploratory and quantitative study on consumer Satisfaction levels and factors influencing consumers towards green products. A hypothetical framework is been presented, and the information is analysed based on the framework of data collection through a structured Questionnaire. The survey was conducted with a sample size of 104 respondents following the data techniques of purposive samplingwhich focused the representatives of all the consumers using green products with the age group 18-50+ respectively. The study used the primary data effectively with the statistical analysis of ANOVA, correlation (both bivariate and partial), and regression through SPSS to provide the exact outcomes.The results of the present study stated that the most of the respondents felt agreeing that the price, health consciousness and the quality factors are most influencing their primary choice towards green products whereas most of the respondents felt neutral for the factor that product influence impacts their primary choice towards green products and hence the product influence factor has less impact. Correspondingly, there is a positive relationship between the variables, green loyalty and dependability comes with customer satisfaction and the more customer is satisfied, the more loyal towards green brand. Further, consumer's belief towards the green marketing or going green has control over the purchase of green products and the frequent purchase of green product. Also revealed that, there is a relationship between the independent variables, consumer's reason for their use of green products and the dependent variable, the purchase of green products is to enhance the development of the environment.

Keywords: Green Products, understanding consumers, environment, development

Introduction

A new evolution to a circular economy can be initiated and completed through the development of a model that aids in progressing the economy. This newly developed model should be capable enough to perform better than the conventional linear models of production and consumption. The linear models would aid in evolving to an enhanced consumption and widespread utilization of natural resources that, in turn, paves the path for enlarged waste, hastened climatic change, ad environmental pollution (Patel, Kumari, Kumari, & Ghosh, 2021). These effects would restrict growth, diminish renewable resources, and negatively impact the ecosystem and human welfare. Recent decades have produced a heavy burden on the environment with an attempt to meet up the demands of the market demands which in turn caused over-exploitation (Lunstrum et al., 2021). Though there are several ways to address the demands, one effective way is to switch to a circular framework of the economy by producing and consuming green products (Bonoli, Zanni, & Serrano-Bernardo, 2021). In this aspect, green products can play a significant role by moving towards a sustainable way of producing and consuming. This can be achieved if the population is well aware of the advantages that can be cherished. This would probably lessen the effect on natural resources. Many of the researches associated with green consumption were observed to be interesting in associated with customer satisfaction which made a huge preference for green products (Ali, 2021).

Green marketing has enabled customers to experience environmentally friendly, ozone-friendly, and recyclable products (Nedumaran, 2020). Notably, green marketing is not restricted to these terms, it has a wider scope of marketing activity that can be implemented for industrial goods, consumer goods, and even services. Services associated with green marketing serve two main purposes where one is to improve the goods, which would demand the customer and reasonable prices and environmentally friendly products that cause minimal damage to natural resources (Fernando, Jabbour, & Wah, 2019). From the overall observation of the existing practices, it is obvious that consumers play a key role in assuring the implementation of green marketing strategies. In association with this, consumer behaviour is considered significant regarding the enforced use of environmentally friendly products (Sun, Li, & Wang, 2022).

Outline on Green marketing
Green products are eco-friendly, bio-degradable, and non-toxic since most of the products are made up of paper, cans, and glasses. The increase in environmental issues has considerably increased people's concerns about environmental welfare (Rangappa, Siengchin, & Dhakal, 2020). These concerns later increased the demand for green products, increasing the novel philosophy of green marketing. From this, more green products are available in the market, and awareness regarding the advantages and disadvantages of green goods has considerably increased (Wong, Wong, & Boon-itt, 2020). These merits and demerits have impacted the willingness of the consumer to buy or deny green products. In association with this, the benefits of using these green products proffer an idea regarding the demands and preferences for green products. People who spend more on green products are the ones who are more concerned about environmental wellness (Ahmed, Zehou, Raza, Qureshi, & Yousufi, 2020). Green products are recycled from food and food products instead of chemical fertilizers. Since consumers and manufacturers are more into the utilization of green products, the awareness regarding the contribution of these products is growing day by day (Hameed, Hyder, Imran, & Shafiq, 2021).

Green consumers behaviours
Consumer behaviour is regarded through the attitude or behaviour through which they search for, use, evaluate, and purchase and disposal the product and services that they expect will meet their demands. Consumer behaviour intends how individuals decide to purchase and spends on resources. Green consumers are the ones who adopt environmentally friendly practices and the ones who purchase green products over regular ones (Nekmahmud & Fekete-Farkas, 2020). Green consumers are more internally regulated as they believe that one individual's usage might influence or affect the protection of the environment. They also realize that the jobs of the protection of the environment should not only be taken care of government but also by each individual who cherishes it. This is largely appreciated since using environmentally friendly products will not affect human health and environmental welfare (Begum, Ashfaq, Xia, & Awan, 2022). Behaviours and attitudes based on the preference for green products vary based on the satisfaction of the individuals with the usage of green products. Satisfaction is largely associated with the price, quality, benefits, knowledge regarding environmental wellness, and concern for environmental development (Melović, Cirović, Backovic-Vulić, Dudić, & Gubiniova, 2020).

Another significant way of marketing green products is green washing, which is a communication that is adopted by organizations and other companies. It aims to put forward arguments regarding enforcing the ecologically responsible image amongst the community. It is concluded that when it is spotted to be the green washed product, it fails the features ofsatisfaction, benefits, and loyalty and becomes a product that bases consumption confusion. Moreover, consumer beliefs and attitudesdemonstrate that they are directed throughthe features of perceivedsatisfaction, benefits, and loyalty and that the observed risk feature is always ignored.(Braga, Martínez, Correa, Moura-Leite, & Da Silva, 2019). Organizations not only prefer green marketing for profit purposes and to gain customer loyalty, but it also aids in improving the sustainability of the planet. Organizations that adapt through their norms would significantly assist in slowing down the climatic change and also promote the conservation of the environment. Though several advantages are pinned along with the utilization of green products, certain criticisms are reported by some consumers who implement the strategies to adhere to the current trends. In addition, an increase in cost is another significant disadvantage pointed out. Since it would occupy many resources to plan and apply new advertising strategies. This again forces organizations to invest in more new technologies and equipment, boosting the expenses. Organizations

must realize the initial investments that can be translated into long-term savings that result from more sustained and increased sales and operations (Hazaea et al., 2022). From extensive analysis, it is obvious that several existing researches have aimed to improve awareness of utilizing green products.

Problem statement

Green products are becoming an essential component nowadays as it makes the environment and lifestyles ecological. As a known fact, green products helps in the consumers health benefits and also have less impact on climate change, so it has changed most consumer buying behaviour and created awareness among consumers of green products. In conducting research, it was clear that most studies have not concentrated on both influencing factors of consumer behaviour and their satisfaction towards green products. Hence, the present study made a peculiar effort to fill those research gaps by focusing on the consumers' satisfaction specifically and also the exact factors influencing consumers to go green which benefits the marketers to develop their organization by understanding the need of the consumers to purchase green products.

Objectives of the study

To examine the consumer's awareness of buying green goods.
To identify the impacting factors on consumers buying behaviour to move them towards the go-green concept.
To determine the level of consumer satisfaction in using green products.

Paper organization

To achieve the purposes, the present research is established in such a way that section 1 commences with the introductory part, section 2 with a literature review where the existing literature is reviewed, section 3 includes the methodology of research, section 4 comes with the results and 5 with discussions, section 6 conveys the limitations of the present study and section 7 concludes the study with section 8 with future recommendations.

Literature review

Consumer awareness of eco-friendly products is getting enhanced. The previous study (Alamsyah, Othman, & Mohammed, 2020) aimed to analyse the correlation between green advertising, consumer green awareness, and green brand image. Data were collected from 102 consumers of superstores in Bandung city through a questionnaire and tabulated through path analysis by SmartPLS. The results show that green awareness among consumers impacts consumers' purchase intentions on eco-friendly products. So, several organizations concentrated on promoting and selling their products with a green marketing strategy. (Gelderman, Schijns, Lambrechts, & Vijgen, 2021) Targeted the effect of strategies on green marketingtowards professional buyers' loyalty and satisfaction. The data were collected from the purchasing managers in "Dutch" manufacturing firms that have kicked into cleaning-related green products recently. The results revealed an effective impact on the loyalty and satisfaction of professional buyers by developing a strategy to create the importance of the price, quality and corporate image of green products. Likewise, to enhance the corporate image and performance of the business, many organizations engaged with green marketing strategies. Using retail giants,Pick n Pay and Woolworths of South Africa, thestudy (Mukonza & Swarts, 2020) adopted a case study. Purposive sampling method was used for collecting data through in-depth interviews and gathering data through questionnaires from top management of certain stores. Added website and document analysis were reviewed for triangular purposes. The correlation was measured using path and content analysis. The results conveyed that a green marketing strategy positively impacts the performance of the business and corporate image.

(Tan, Ojo, & Thurasamy, 2019) Investigated to identify the elements which may influence the buying behaviour of young consumers in Malaysia toward green products. Data were gathered through a questionnaire from 217 participants aged between 18 -25, and to analyse, the conventional technique of sampling was used. The outcome of the analysis denoted that eco-label, environmental consciousness, advertising, and pricing were the important interpreters to develop the consumer's buying behaviour on green products. Similarly, (Widyastuti, Said, Siswono, & Firmansyah, 2019) Purpose was to understand public awareness of consuming green products. The study collected data through a survey from Unilever consumers. The purposive Sampling method was used to sample about 225 consumers in Jakarta. The

result conveyed that by installing the process of green marketing into the marketing strategy, Unilever has created a good corporate image among the public.

The waste disposal of plastic in the ocean of Indonesia created a severe issue as it kills plenty of animals in the sea and makes the environment unhealthy. The purpose of the study (Ramli, Permana, Soelton, Hariani, & Yanuar, 2020) was to examine and install green marketing in fast-food hotels to create awareness among consumers regarding the harmfulness of using plastic bags or products and to restrict fast food hotels. The data collection was done through a questionnaire from the participants of Jakarta. Purposive random sampling was used to determine the sample, and the analysis of data used partial least square. The outcomes showed that both consumer behaviour and attitude positively affect green marketing, and consumer behaviour has the most important effect on consumer awareness of green marketing. Therefore, human is responsible for the rise of pollution in the world. Hence, another author (Khan, Saengon, Alganad, Chongcharoen, & Farrukh, 2020) targeted to examine a model which could benefit change consumers' behaviour into consumers' green behaviour. Data were gathered from consumers in Malaysia (Cyberjaya) and Thailand (Bangkok). 320 participants were given questionnaires, and only 215 were filled by the participants. Non-probability techniques were used. The result was that both attitude and knowledge have a significant relationship in positively impacting the green behaviour of consumers, and the ban on plastic bags policy implemented by the government also positively impacted the development of the consumer's eco-friendly behaviour.

(Indriani, Rahayu, & Hadiwidjojo, 2019) Aimed to evaluate the relationship between green brand image and environmental knowledge on green products and purchase intention of green products in raising awareness in purchasing eco-friendly products for cosmetic and body care. The data were collected from the state university students in Manado, Indonesia, quantitative analysis was used, and SmartPLS was used for analysis. The results indicated no major association between consumers' green purchase intentions and environmental knowledge. However, the attitude was a complete intervention effect on the relationship between consumers' green purchase intentions and environmental knowledge. Similarly, another author (Chen, Chang, Li, & Chen, 2020) evaluated the effect of green brand impact on green purchase intents and discovered the mediation effect of green brand associations and attitudes in terms of the Structural Equation Model (SEM). Its objective was to focus on Taiwanese consumers with experience purchasing electronic products. A total of 1000 consumers were targeted, and out of that, 365 valuable responses were gathered through a questionnaire survey and SEM. The outcome disclosed that the effect of the green brand has no impact on the purchase intents of green products and indicated that green brand attitudes and associations completely intervene the relationship between the effect of green brand and the purchase intents of green products.

(Rustam, Wang, & Zameer, 2020) Investigated the potential impacts of corporate environmental sustainability towards green consumerism. The primary data was gathered using the questionnaire method, and secondary data was gathered from the organization's annual records and the database of global reporting initiatives. To access the data, multiple regression techniques were used. The outcomes pointed out that the sustainability exposure of the organizations and environmental responses create green consumption practices among consumers.

Research gaps
One of the research (Widyastuti et al., 2019) has concentrated only on one company rather, it may extend to another area of manufacturing or private sectors. Another study (Ramli et al., 2020) focused only on the plastic waste that affects the green environment, instead, it can be made considered that the other sorts of waste also as all the wastes needed to be controlled in order to protect the environment. Similarly, (Khan et al., 2020) was done only based on the ban on plastics, further, the predictors were selected only based on knowledge and attitude towards the green behaviour of the consumer, rather it can focus the other wastes and predictors. (Indriani et al., 2019)limited only to the Indonesia State Universities and does not concentrate on other consumers in various areas.

Research Methodology
This section will brief about the method of research used in this study. This study aims to analyze the customer satisfaction level and the factors impacting consumers toward green products. In the present study, primary data is used by a quantitative method, which is fetched through questionnaires.

Quantitative methods are used as it is strong at reviewing large sets of public and creating generalities from the sample being considered to larger sets outside the sample (Holton & Burnett, 2005). Quantitative analysis uses statistical methods with the samples collected through a structured questionnaire to justify the research objectives and framed hypothesis.

Research Design
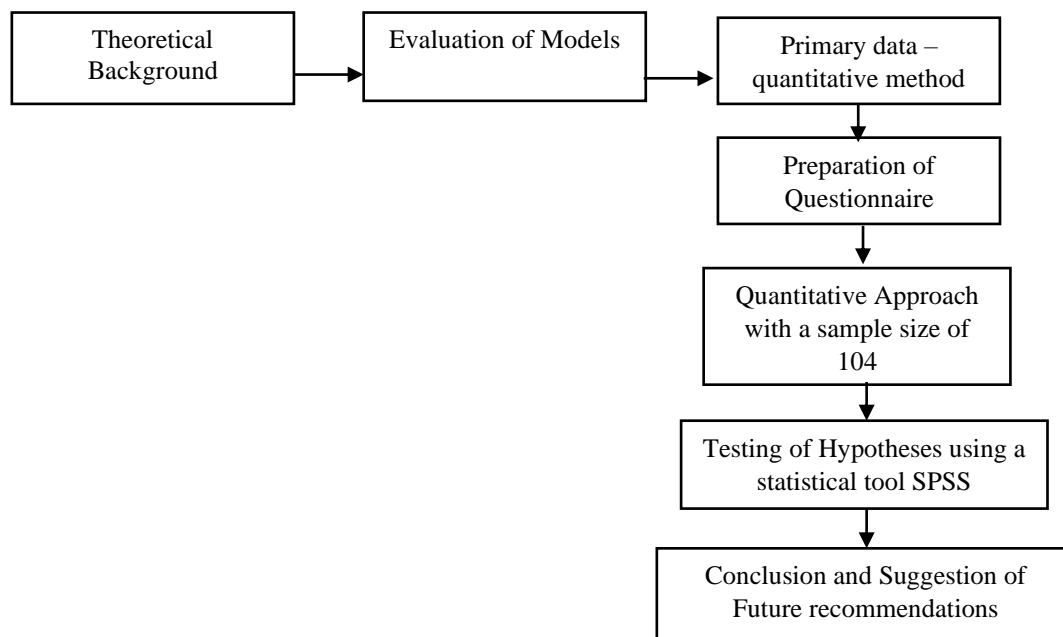
Figure 1 Research design

Variable definition
Investigators often work or exploredependent and independent variables in their studies to calculate the relations of cause and effect. The cause is the Independent variable, hence it rests independent among other variables. The effect is the dependent variable, therefore it depend on the Independent variable.

As a known fact, the study aimed to analyze consumer Satisfaction levels and factors influencing consumers towards green products.

Independent variables
The present study has considered the green products and the consumer's purchasing green products as the independent variables.

Dependent variables
The present study has considered the factors influencing the consumers towards green products and the customer's satisfaction level towards green products as the dependent variables.

Hypothesis
H1: There are certain awareness existing among consumers regarding the purchase of green products.
H2: There are some factors that influence the consumers to the concept of going green.
H3: There exists a significant relationship between consumer satisfaction and green products.

Research Instruments
The research instrument is referred to as a tool that is used to calculate, examine and gather data based on the research interests which is being proposed. The research used a quantitative approach. The quantitative method used a structured

questionnaire as a research tool featuring the structure of questions engaged in collecting valuable data from the participants. These tools were especially effective in computing customer satisfaction and influencing consumers toward green products.

Data Collection

The sample size used in the present study is 104 participants by purposive sampling technique for the quantitative approach through a structured questionnaire which focused on the representatives of all those consumers using green products from the age group of 18-50+ and above accordingly to be more manageable.

Data Analysis

The quantitative method used a statistical tool called Statistical Package for Social Science (SPSS) excel for examining the correlation, regression, and ANOVA analysis based on the respondent's data in the structured questionnaire.

Ethical Considerations

The research respondents will be informed clearly about the purposes of the study. They will be assured that the information gathered is strictly for educational purposes and that all the particulars will be kept confidential. The date and time for the data gathering through a questionnaire.

Results

The numerical results using quantitative research methodology have been shown in this section. Responses collected from the target respondents were calculated using SPSS. These outcomes formulated are represented in the form of charts and tables in this section.
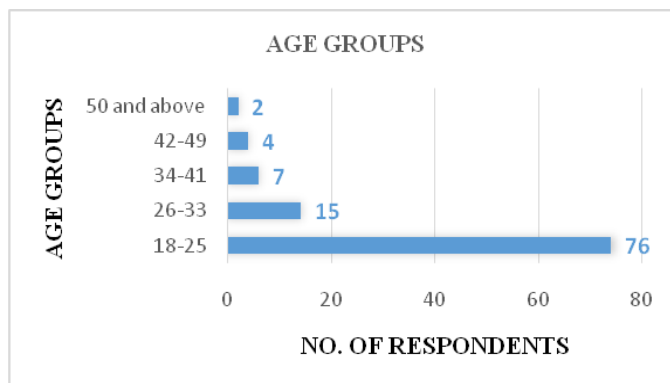
Figure 2 Respondents age groups

From figure 1, the age groups of the respondents and the highest respondents are from which group can be observed. Out of 104 respondents, around 76were between the age group of 18-25 that indicates the more number of next generation population.
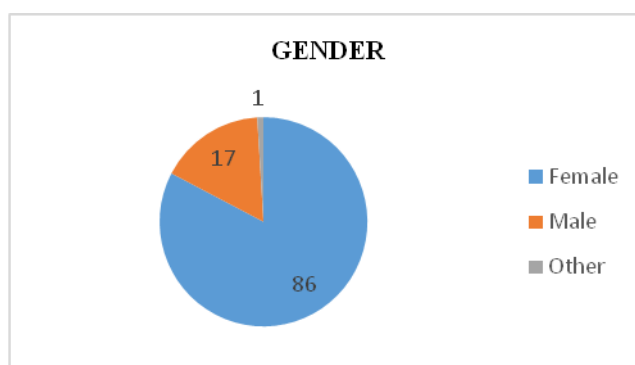
Figure 3 Respondents count based on gender

Out of 104 respondents, around 83were female which implies the awareness of the products and the well-organized purchase behavior in women.
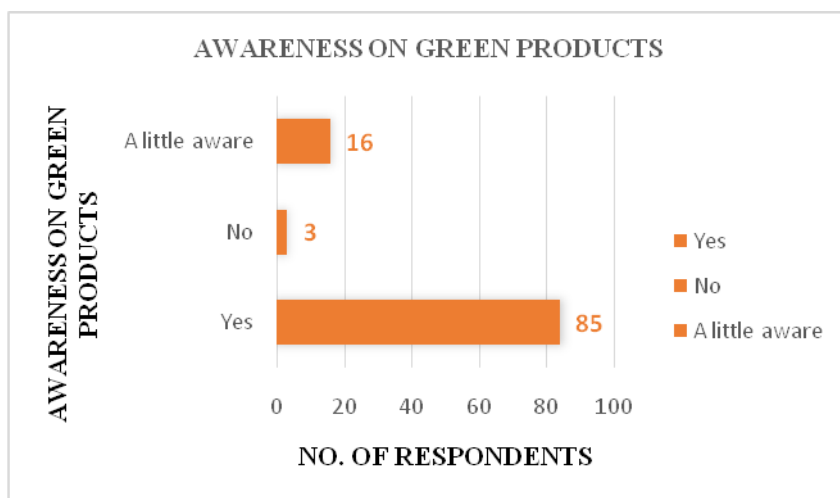
Figure 4 Awareness of green products

From the above figure 3, the awareness regarding green products among the respondents can be identified. From the total of 104 respondents, it can be inferred that around 84 were completely aware of green products and hence it can confessed that since most of the respondents are female and young, they might be updating their knowledge towards the recent trends and the good/bad products.

Quantitative results
Results formulated and extracted from the SPSS tool have been listed in this section. Furthermore, to compute the customer satisfaction level and the factors impacting consumers towards green products, certain statistical analyses such as ANOVA, Regression, and Correlation analysis have been performed.

Table 1 ANOVA Descriptive

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Factors affecting your purchase decision? [Price]	disagree	5	2.20	.837	.374	1.16	3.24	1	3
	neutral	40	1.83	1.281	.203	2.09	2.91	1	5
	agree	59	2.50	.950	.124	1.58	2.08	1	5
	Total	104	2.11	1.123	.110	1.89	2.32	1	5
Factors affecting your purchase decision? [Health Factor or Role of Consciousness]	disagree	5	2.80	1.304	.583	1.18	4.42	2	5
	neutral	40	1.68	1.339	.212	2.10	2.95	1	5
	agree	59	2.53	.937	.122	1.43	1.92	1	5
	Total	104	2.06	1.197	.117	1.82	2.29	1	5
Factors affecting your purchase decision? [Quality]	disagree	5	2.60	1.517	.678	.72	4.48	1	5
	neutral	40	1.68	1.358	.215	2.02	2.88	1	5
	agree	59	2.45	.880	.115	1.45	1.91	1	4
	Total	104	2.02	1.174	.115	1.79	2.25	1	5
Factors affecting your purchase decision? [product Influence]	disagree	5	2.40	1.140	.510	.98	3.82	1	4
	neutral	40	3.00	1.109	.175	2.65	3.35	1	5
	agree	59	2.61	.831	.108	2.39	2.83	1	4
	Total	104	2.75	.973	.095	2.56	2.94	1	5

Independent variable: Green products have become the primary choice for consumers in present day world.

Table 1 clearly explains the independent variable that is the consumers choosing green products as their primary choice considering the dependent variable, the factors that influencing them to consider the green products as their primary choice such as price, quality, health consciousness and product influence. The acquired data has shown in the tabulated layout. From the results, the highest mean value (2.50), (2.53) and (2.45) implies that most of the respondents felt agreeing thatthe price, health consciousness and the quality factors are most influencing their primary choice towards green productswhereas the highest mean value (3.00) denoted that most of the respondents felt neutral for the factor that product influence impacts their primary choice towards green products and hence the product influence factor has less impact.

Table 2 ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Factors affecting your purchase decision? [Price]	Between Groups	10.731	2	5.366	4.550	.013
	Within Groups	119.105	101	1.179		
	Total	129.837	103			
Factors affecting your purchase decision? [Health Factor or Role of Consciousness]	Between Groups	19.997	2	9.999	7.911	.001
	Within Groups	127.656	101	1.264		
	Total	147.654	103			
Factors affecting your purchase decision? [Quality]	Between Groups	15.980	2	7.990	6.406	.002
	Within Groups	125.981	101	1.247		
	Total	141.962	103			
Factors affecting your purchase decision? [product Influence]	Between Groups	4.266	2	2.133	2.311	.104
	Within Groups	93.234	101	.923		
	Total	97.500	103			

Table 2 shows the outcomes attained through ANOVA. The significant values attained for the measured concepts are 0.013, 0.001, 0.002 and 0.104. As for the price, health consciousness and quality factors, the significant value is less than 0.05, which is the default p-value, there exists a significant relationship among independent groups. This denotes that the reason representing the consumers choosing green products as their primary choicehas significant impact on these factors whereas for the product influence factor, the significant value is more than 0.05 which determines the less significant relationship among the independent groups.

Table 3 Correlations (Bivariate)

		Green Loyalty and Dependability comes with consumer satisfaction?	The more customer is satisfied, the more loyal towards the green brand?
Green Loyalty and Dependability comes with consumer satisfaction?	Pearson Correlation	1	.262**
	Sig. (2-tailed)		.007
	N	104	104
The more customer is satisfied, the more loyal towards the green brand?	Pearson Correlation	.262**	1
	Sig. (2-tailed)	.007	
	N	104	104
**. Correlation is significant at the 0.01 level (2-tailed).			

Analysing correlation in data exploration is a statistical method used to calculate the power of the correlation or relationship among the measured factors and calculate their association through the significant coefficient value of Pearson. The results shown in table 3 are the results intended by considering the responses of 104 participants who were

using green products.When the Pearson correlation coefficient values of the variables are observed to be the same, they are positively correlated. The Pearson coefficient value 0.262 represent that there is a positive relationship between every considered variable with every other variables. Here, there is a positive relationship between the variables, green loyalty and dependability comes with customer satisfaction and the more customer is satisfied, the more loyal towards green brand. Hence, there occurs relationship between the considered variables as the significant value is also less than 0.05 which is the default p value.

Table 4 Correlations (Partial)

Control Variables				Did you ever purchase a green products?	How frequently do you purchase green products?
Do you believe in concept of "green marketing or going green"?	Did you ever purchase a green products?		Correlation	1.000	-.222
			Significance (2-tailed)	.	.024
			df	0	101
	How frequently do you purchase green products?		Correlation	-.222	1.000
			Significance (2-tailed)	.024	.
			df	101	0

The outcomes shown in table 4 are the results intended by considering the responses of 104 participants who were using green products.Once the significant coefficient values of two or more variables are perceived to be equal to the control variables, they are positively correlated with one another. The consumer's belief towards the concept of green marketing or going green have been chosen as the control variable. The correlation coefficient of the parameters representing the purchase of green products and the frequent purchase of green products is 1.000 and hence the controlling variable here controls these two parameters. This shows the positive relationship among the variables. As the significant valueis 0.00, this signifies that theconsumer's belief towards the green marketing or going green will make them to purchase the green products and also make them to frequently rely on them.

Table 5 Regression analysis-Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.453a	.205	.193	.363
a. Predictors: (Constant), Why do we use green products?				

From the outcomes shown in table 5 above, the R2 value discloses the relation among the dependent variable and its factors measured for regression analysis. When 100 is multiplied by the R-value 0.205, the appropriate percentage value of the relation can be calculated. Therefore, it has been observed that 20.5% of the predictor variables that represents the consumer's reason for their use of green productscontributed effects to the dependent variable, the purchase of green products is to enhance the development of the environment and thus the consumer's purchase decision towards green products is mostly happening considering their health benefits which may simultaneously benefits the environment also.

Table 6 Regression analysis-ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.148	1	2.148	16.278	.000b
	Residual	8.313	63	.132		
	Total	10.462	64			
a. Dependent Variable: Does the purchase of green products enhance the development of environment?						
b. Predictors: (Constant), Why do we use green products?						

In the above table 6, as the significant value of regression is 0.00, it is been observed that the predictors and the dependent variables are relatively contributing effects to each other.

Table 7 Regression analysis- Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.180	.094		23.143	.000
	Why do we use green products?	-.249	.062	-.453	-4.035	.000
a. Dependent Variable: Does the purchase of green products enhance the development of environment?						

The outcomes of the ANOVA contributed to the analysis of regression have been shown in the above table 7. There is a relationship between the independent variables,consumer's reason for their use of green products and the dependent variable,the purchase of green products is to enhance the development of the environmentsince the significant value is 0.00 which is less than 0.05 (default p value).

Discussions

Awareness and the factors impacting consumer satisfaction toward the purchase of green products have gained good attention among researchers. In the present study, out of 104 respondents, around 76were between the age group of 18-25 that indicates the more number of next generation population and around 83were female which implies the awareness of the products and the well-organized purchase behavior in women. Also it can be inferred that around 84 were completely aware of green products and hence it can confessed that since most of the respondents are female and young, they might be updating their knowledge towards the recent trends and the good/bad products.The results of the present study stated that the most of the respondents felt agreeing that the price, health consciousness and the quality factors are most influencing their primary choice towards green products whereas most of the respondents felt neutral for the factor that product influence impacts their primary choice towards green products and hence the product influence factor has less impact. Correspondingly, there is a positive relationship between the variables, green loyalty and dependability comes with customer satisfaction and the more customer is satisfied, the more loyal towards green brand. Further, consumer's belief towards the green marketing or going green has control over the purchase of green products and the frequent purchase of green product. Also revealed that, there is a relationship between the independent variables, consumer's reason for their use of green products and the dependent variable, the purchase of green products is to enhance the development of the environment.

Similar to the present study, the researcher (Alamsyah et al., 2020) aimed to analyse the correlation between green advertising, consumer green awareness, and green brand image. The result revealed that green awareness among consumers impacts the purchase intents of consumers on eco-friendly products. Likewise, another research (Tan et al., 2019) investigated identify the factors which may influence young consumer's buying behaviour in Malaysia towards green products, and the results of the analysis denoted that eco-label, environmental consciousness, advertising, and pricing were the important interpreters to develop the consumer's buying behaviour on green products. Similarly, (Wang, Ma, & Bai, 2019) aim was to study the connection between the green products awareness and their purchase intentions. The result showed that green trust partially relates to the awareness and purchase intentions of green products. (Ansu-Mensah, 2021) evaluated the awareness among the university students and the factors impacting them towards the purchase intention, and the result concluded that the awareness of green products highly impacts the students towards the purchase decision by the value, price, and quality.(Suhaily & Darmoyo, 2019) Analysed the effect of green product advertising on the loyalty and satisfaction of the consumer's purchase decision, and the result came that the purchase decision has a direct impact on consumer satisfaction, and the consumer satisfaction has a direct influence on consumer loyalty.

Though several studies have aimed to research the factors influencing consumer and their satisfaction towards green products, with the statistical analysis of ANOVA, correlation (both bivariate and partial), and regression through SPSS, the present study has effectively used primary data by aiming to focus on both the consumer satisfaction and also the factors impacting consumer purchase intention towards green products mainly focusing on the consumer's health consciousness which is considered significant.

Limitations and Future recommendations

Every study has its limitation so does the present study. The study has focussed only on small samples, instead, the samples can be collected widely. However, the study concentrated on the impacting factors of consumers towards the purchase intention of green products, the future study can also concentrate on other factors. In future, the research can be done in both quantitative and qualitative method in order to get the in depth results.

Conclusion

The present study focussed on the factors impacting consumer purchase intention towards green products and consumer satisfaction towards green products. The research used a quantitative approach. The sample size used in the present study is 104 respondentsby means of purposive sampling technique for the quantitative approach through a structured questionnaire featuring structure of questions engaged in collecting valuable data from the participants, which focused the representatives of all the consumers using green products with the age group of 18-50+ accordingly to be more manageable. The study's overall results revealed that major participants have awareness towards green products and its welfare. Mainly stated that the reason representing the consumers choosing green products as their primary choice has significant impact on the price, health consciousness and the quality factors rather than the product influence factor. Similarly, there is a positive relationship between the variables, green loyalty and dependability comes with customer satisfaction and the more customer is satisfied, the more loyal towards green brand. Further, consumer's belief towards the green marketing or going green has control over the purchase of green products and the frequent purchase of green product. Also revealed that, 20.5% of the predictor variables that represents the consumer's reason for their use of green products contributed effects to the dependent variable, the purchase of green products is to enhance the development of the environment and thus the consumer's purchase decision towards green products is mostly happening considering their health benefits which may simultaneously benefits the environment as well.

Future recommendation

Future researchers could inspect some particular green products and relate them to the purchase intentions of the consumers and their satisfaction with various green products.

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ARTIFICIAL INTELLIGENCE AND ITS IMPLEMENTATION IN E-COMMERCE WITH SPECIAL REFERENCE TO ONLINE SHOPPING

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Abstract

With the advent of information and communication technologies, artificial intelligence (AI) has become an increasingly popular tool in e-commerce development. In today's e-commerce world, companies are eager to influence customer behavior in favor of certain products and brands. Machine learning and deep learning are two of the most common tools used in artificial intelligence. Businesses, government agencies, and individuals utilize these tools to anticipate and learn from data. Artificial intelligence may seem like an innovative tool for achieving this goal, but there are still issues of concern whether this kind of technology is beneficial or not. Artificial intelligence has changed Indian e-commerce, for better or worse. It looks at its applications in different areas of e-commerce and the ways it has helped e-commerce websites to provide a better user experience. In order to measure this customer experiences from their perspectives and analyzed to provide the Artificial intelligence tools that would entice the shopping experience on the other hand, an overall rate of online shopping has been increased with the extensions of AI tools that make it easier to locate the respective products. Using these features have seem to be more demanding and suggestions for improvements are utilized in the adoption of AI in e-commerce. To ensure the customer's needs and satisfaction, studies have been done to make each step closer to quickness, flexibility, and quality. The present study primarily evaluates the and its significance within the context of e-commerce based on available studies on this issue. Customers challenges and problems have been taken into consideration to give an overview of the enhancement needed for AI features. The study has been made to study the awareness of AI tools and their usage status among customers while online shopping and also challenges and problems faced by the customers while using AI tools.

Keywords: Artificial Intelligence, E-commerce, AI tools, AI Awareness, Online Shopping.

INTRODUCTION

When it comes to artificial intelligence (AI), people often think of advanced robotics or other futuristic technology. However, in the e-commerce sector, AI is less about human-like robots and more about learning technologies and algorithms that provide a foundation for businesses. Artificial intelligence is the ability of computers to perform tasks that require human intelligence, including visual perception, speech recognition, and decision-making. It's an IT industry that works with machines that can imitate human behavior. AI technology and its role in modernising e-commerce (Anil kumar, Sahu & Ajay Kumar, 2022). AI can help today's online retailers to deliver an optimized customer experience by using collected business and customer data to make better decisions and predict the future business more accurately, which would make the shopping experience to consumers' satisfaction. This can be done on and off their e-commerce websites. As e-commerce is one of the top growing business in India and provides a great market potential for

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investments, foreign investors are finding e-commerce sector (Mahipal & Sankaraiah, 2022) By incorporating AI into their business, retailers can stay ahead of the competition and provide their customers with a seamless shopping experience.

The exponential advancement of digital technology is due to cognitive capacity of artificial intelligence. The field of intelligent machines has grown substantially throughout the prior ten years. This study has been focused on the business, culture, industry, and daily life, in which AI is playing an integral part. We engage with AI every day, often without recognizing it, in a variety of ways, from deep learning to natural language processing. Many of the most repetitive operations now carried out by humans can already be completed faster and more accurately by AI. However, AI is not just found in robots. With the aid of AI, humans will be able to move into better, more skilled positions; all they need is a little training and knowledge (Shravani, 2023).

In e-commerce and financial industries, to design standard, reliable methods for product quality control and the search for new ways of reaching and serving customers, while also lowering costs, AI has been deployed to achieve better customer experience, efficient supply chain management, improved operational efficiency and reduced manufacturing times. The role of online marketing is expanding in the context of accelerated digitization significantly, as more and more companies are investing in e-commerce activities. In addition to this there have been significant changes in customer behavior and leading to profitability as such, these investments are motivated by the fact that they are easier to measure compared to those of traditional marketing. And with the addition of artificial intelligence, significant enhancements brought out demand for online shopping more than traditional shopping. In accordance with a most recent study, AI in e-commerce continues to expand at such a rapid pace that AI revenue is expected to reach $36.8 billion globally by 2025.

Source: Tractica

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REVIEW OF LITERATURE

Vishal Dineshkumar Soni (2020) Emerging roles of artificial intelligence in e-commerce. The study focused on the uses of AI in e-commerce and found that customers are becoming more interested in AI as they learn how it can help them excel in their e-commerce business. It is also found that the AI aids in real-time human interaction between the client and the customer, via messengers, chatbots, voice chats, and other means. Eliza Nichifor, Adrian Trifan, and Elena Mihaela Nechifor (2020) Artificial Intelligence in e-commerce: basic chatbots and the consumer journey. The purpose of this study was to see how artificial intelligence used through chatbots affects online retail in terms of the content used for communication. This new perspective extends the two elements of perceived utility and perceived ease of use by adding measures to create a high level of interaction via chatbots. Harikumar Pallathadka, Edwin Ramirez-Asís, Telmo Pablo Loli-Poma, and Karthikeyan Kaliyaperumal (2021) Applications of artificial intelligence in business management, e-commerce, and finance. There is a lot of potentials for machine learning and artificial intelligence to enhance e-commerce operations. In this study they explored a some of the most common ways that these technologies are being used, including sales growth, profit maximization, sales forecasting, inventory management, security, fraud detection, and portfolio management. Another Study on the role of AI in e-commerce and its application the different areas of e-commerce (Shyna Kakkar & Vishal Monga, 2017).

Ambar Srivastava (2021) The Application and impact of artificial intelligence (AI) on e-commerce, found that businesses are using AI to better manage market demand and are collaborating with various organizations to combine their AI capacities. In the coming years, virtual intelligence technology is likely to benefit the e-commerce industry. Diptikanta Panigrahi and Meher Karuna (2021) made an attempt to study how artificial intelligence leverageng to enhance business engagement in e-commerce. The purpose of this research study was to analyze the implications of artificial intelligence (AI) in the e-commerce business and to identify areas where AI can be implemented to enhance user experience and engagement. It was concludes that AI is indeed an indispensable component for enhancing business engagement in e-commerce. Ayyapparajan & Sabeena (2022) Artificial intelligence has the effective capacity to accumulate and examine huge volumes of records and provide selections for action. E-trade is now adopting this generation to perceive styles primarily based totally on browsing, buy history, credit score checks, account statistics etc. These facts amassed then shape the premise of making custom designed pointers for every customer. Google and Microsoft are already making an investment into new AI initiatives. Many e-trade companies have commenced imposing one of kind of AI to higher recognize their customers, and offer a greater purchaser experience. This paper highlights the position of synthetic intelligence in e-trade and its software in one of kind regions of e-trade.

Prabha (2021) made an attempt to examine how artificial intelligence (AI) is a way of making a computer controlled robot or software think intelligently in the similar manner the intelligent humans think. This study focused on the impact of AI in e-commerce. E-Commerce is now adopting various technologies to identify patterns based on the buying and selling of goods or services using the internet and the transfer of money and data to execute these transactions. The
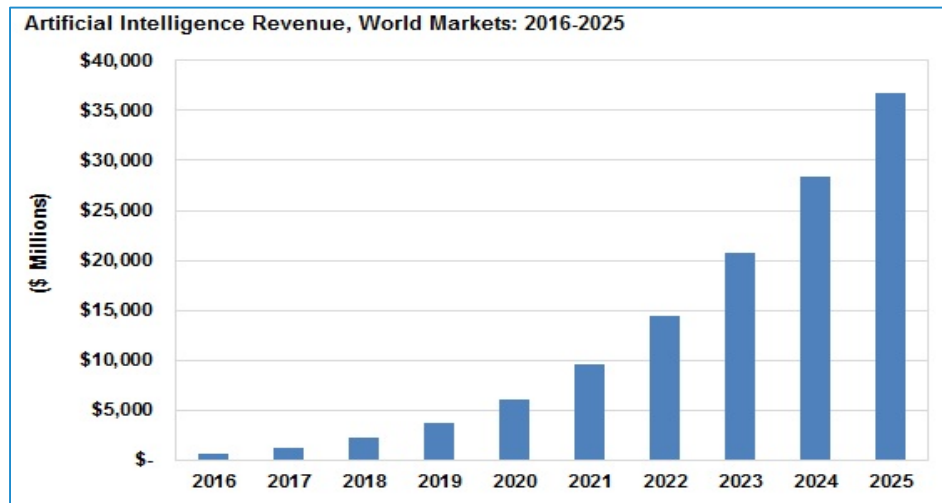
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result and suggestion that AI applications can generate and predict the accurate forecast of the e-commerce. This paper highlights the impact of AI in e-commerce and its applications in different areas of e-commerce. It concluded that the AI has helped e-commerce websites in providing with better user experience. Sarita, Harsh Kumar, Satish Kumar Mishra, Munish Swaroop (2022) Internet shopping is changing by utilizing AI to anticipate the things that clients will buy and when they will get them, thereby anticipating their shopping patterns. The purpose of this study is to explore the benefits and legal impacts of AI in e-commerce as well as factors that contribute to the transformation of the industry. By using a questionnaire, a convenience sampling (non-probability) of 100 entrepreneurs in Bangalore was used to collect the necessary data. To identify the significant factors that impact the transforming role of AI in e-commerce, a t-test was used. A t value > 0 and a sigma < .05 rule were used to detect significant factors. Therefore, out of six factors, three factors such as media attention competitive pressure and digital maturity were found to be significant. Three factors could not be identified as significant, such as time saving, marketing strategy and decision making.

Need For And Significance Of The Study

The ever-growing industry and e-commerce, especially during the covid-19 pandemic period had gained lot of   popularity, it is AI features that are applied in the websites of local, national, and international to capture the market. This attracted more people into engaging in online shopping and as such there are certain needs and significance that AI tools have played according to the customer's perception for making their online shopping experience more enhanced and safer as well as quick. Such advancements have catered to the needs and enthusiasm of the customers. However, such drive also questioned the stability of the adoptions and whether this is beneficial to society as a whole. This has been overlooked from both perspectives of the seller and customer. Therefore, the need arose for the study to be carried on to understand the reason for the implementation of AI in online shopping specifically addressing the features or tools that have been adopted to make online shopping easier and the challenges or issues that are faced by the customers. Also, to understand the role of AI tools and its impact on their online shopping experience. Hence, this study attempts to identify the level of awareness and online shopping experiences by using AI as a e-commerce tool.

Statement Of The Problem

Online shopping is expanding significantly with the addition of adopting artificial intelligence, significant enhancements brought the demand for online shopping more than traditional shopping. However, rapid change is leading to the inexistence of awareness of such adoptions among customers, and with the technological advancements in online shopping, challenges are faced in the functioning of AI tools in online shopping. Thus, a wide variety of literature sources and the successful survey responses received have completed the theoretical and empirical research. Carrying out the literature review, certain studies relevant to the topic like 'The increasing importance of AI applications on e-commerce', 'Artificial Intelligence and its applications in e-commerce have been reviewed. However, a study specific to a region was proposed to be relevant.

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Thus, a present study was carried on because of the above problem which was identified to understand the AI implementation in online shopping and the usage of AI tools with a specific focus on the customers of Hyderabad city.

OBJECTIVES OF THE STUDY

The main aim of the study is to realize the following objectives

1. To study the awareness among the customers about artificial intelligence (AI) tools among different gender, age, qualification & occupation groups;

2. To analyze the usage of artificial intelligence tools during online shopping among the genders; and

3. To find out the problems faced by the customers while using of AI tools by different gender, ages, qualification, and occupation groups.

Hypotheses

The following null hypotheses were framed in tune with above objectives

1. There is no awareness of AI tools among different gender groups, ages, qualifications & occupation groups.

2. There is no significant association between the usage of voice-based shopping, virtual 3D try-on, product recommendation, chatbots, live chats, call customer executives, digital virtual assistants, and filter tools among the gender group.

3. There is no significant association between the problems faced when using AI tools by different gender, ages, qualification, and occupation groups.

RESEARCH METHODOLOGY

The methodology used for the present study is primary data which was collected through an online questionnaire by using google forms. In case of secondary data, through qualitative literature, web-based research journals, articles, research papers, etc., has been used. The sample size was 200 and has considered both men and women who does online shopping. The sampling techniques adopted in this study was non-random sampling. The collected data was analyzed by using ANOVA, Chi-square, and Correlation tests using SPSS software.

Data Analysis and Interpretation

In this section, an attempt has been made to analyse the sample data includes 200 people of various ages, genders, education levels, and occupation levels. The majority of respondents (71%) were females. In terms of age, 63% of respondents were under the age of 25 years. Where as 97.5% of those polled were educated. About half of the respondents are working professionals, while the other half are not. Hence, it can be concluded that the majority of women and are young customers shopping online, most of them are educated and working.

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Table 1: Demographic Profile Of The Respondents

	Options	No. of Respondents	Total	Percentage (%)
Gender	Male	58	200	29
	Female	142	200	71
Age	Below 25	126	200	63
	Above 25	74	200	37
Qualification	Educated	195	200	97.5
	Uneducated	5	200	2.5
Occupation	Working	100	200	50
	Not working	100	200	50

Source: Field data

Objective-1: To study the awareness about artificial intelligence tools among different gender, age, qualification & occupation groups.

H_0 : There is no awareness of artificial intelligence tools among different gender groups, ages, qualifications & occupation groups.

Table 2: Awareness of AI tools among the demographics section (ANOVA)

Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.00	1	0.00	0.00	0.953
Within Groups	139.68	198	0.71		
Total	139.68	199			
Between Groups	5.52	1	5.52	8.14	.005
Within Groups	134.16	198	0.68		
Total	139.68	199			
Between Groups	1.09	1	1.09	1.55	0.215
Within Groups	138.59	198	0.70		
Total	139.68	199			
Between Groups	2.88	1	2.88	4.17	0.043
Within Groups	136.80	198	0.69		
Total	139.68	199			

Source: Field data

The above table depicts the awareness of customers towards AI tools among the different gender groups, ages, qualifications & occupation groups. This statistic shows the mean square between the groups and within the groups. The F-value and the Sig (p-value) are shown. The P-value is greater than the significant value of 0.05 (P>0.05). Hence, the null hypothesis is accepted. This could be inffered that there is no awareness of artificial intelligence tools among qualification and gender groups. Whereas there is adequate level of awareness of artificial intelligence tools among age and occupation groups.

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Objective-2: To analyze the usage of artificial intelligence tools during online shopping among the genders.

H_0: There is no significant association between the usage of voice-based shopping, virtual 3D try-on, product recommendation, chatbots, live chats, call customer executives, digital virtual assistants, and filter tools among the gender group.

Table 3: The Usage Of Ai Tools Among Genders Groups

Chi-square test									
		Never	Rarely	Some-times	Often	Always	Total	Chi-square test value	
Gender	Female	3	67	8	43	21	142	C.V.	14.54
	Male	6	15	4	17	16	58	df	4
	Total	9	82	12	60	37	200	Sig	0.006
Gender	Female	5	56	8	44	29	142	C.V.	10.32
	Male	6	13	7	16	16	58	df	4
	Total	11	69	15	60	45	200	Sig	0.035
Gender	Female	24	19	28	34	37	142	C.V.	0.90
	Male	12	9	9	13	15	58	df	4
	Total	36	28	37	47	52	200	Sig	0.925
Gender	Female	3	35	14	40	50	142	C.V.	24.13
	Male	9	7	12	20	10	58	df	4
	Total	12	42	26	60	60	200	Sig	0.000
Gender	Female	5	42	21	32	42	142	C.V.	9.00
	Male	7	9	7	16	19	58	df	4
	Total	12	51	28	48	61	200	Sig	0.061
Gender	Female	10	33	27	38	34	142	C.V.	9.64
	Male	9	9	6	12	22	58	df	4
	Total	19	42	33	50	56	200	Sig	0.047
Gender	Female	23	29	22	31	37	142	C.V.	4.66
	Male	10	8	16	10	14	58	df	4
	Total	33	37	38	41	51	200	Sig	0.324
Gender	Female	42	31	21	25	23	142	C.V.	3.74
	Male	12	11	12	9	14	58	df	4
	Total	54	42	33	34	37	200	Sig	0.442

Source: Field data

It is an evident from the above table that the usage of voice-based shopping, virtual 3D try-on, product recommendation, chatbots, live chats, call customer executives, digital virtual assistants, and filter tools among the gender group. The value of the chi-square statistic and Sig value are shown. According to the statistic table, the P-value is greater than the significant value at 5% (P>0.05). Hence, the null hypothesis is accepted. This could be inffered that there is no significant association between the usage of filter tools, digital virtual assistants, live chats & product recommendations tools among different gender groups.

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Objective-3: To find out the relationship between the challenges and problems faced by the customers while using AI tools by different gender, ages, qualification, and occupation groups.

H_0: There is no significant association between the *challenges and* problems faced by the customers while using AI tools by different gender, ages, qualification, and occupation groups.

Table 4: Challenges And Problems Faced In The Demographics Section

CORRELATION					
	Challenges faced	Gender	Age	Professional Qualification	Occupation
Pearson Correlation	1	-0.76	0.15	0.22	-0.07
uSig. (2-tailed)		0.287	0.838	0.757	0.322
	Problems faced	Gender	Age	Professional Qualification	Occupation
Pearson Correlation	1	-0.1	0.065	-0.15	0.035
Sig (2-tailed)		0.886	0.361	0.834	0.624

Source: Field data

The above table shows that the *challenges and* problems faced by the customers of different gender, ages, qualifications, and occupation groups. The value of the correlation for *challenges and* problems faced and the Sig value is shown. According to the statistic table, the P-value is greater than the significant value of 5% ($P>0.05$). Hence, the null hypothesis is accepted. This could be inffered as that there is no significant association between the *challenges and* problems faced by the customers while using AI tools among different gender, age, qualification, and occupation groups as well.

CONCLUSIONS AND SUGGESTIONS

AI tools existence has an awareness among the majority of customers who shop online and come across these tools. Advanced tests have been applied to study the level of awareness of these AI tools, especially among the different gender groups and qualification groups. There are about eight (8) AI tools mentioned in this study which were used to find out their usage among the customers. It is inferred that most of the AI tools are opted by customers to make their online shopping made easy. Even if one or two have been less or never been used, it does still show that their usage is active in online shopping. This study concluded that i) there is no awareness of artificial intelligence tools among qualification and gender groups. Whereas there is awareness of artificial intelligence tools among age and occupation groups, ii) there is no significant association between the usage of filter tools, digital virtual assistants, live chats & product recommendations tools among different gender groups and iii) there is no significant association between the *challenges and* problems faced by the customers while using AI tools among different gender, age, qualification, and occupation groups. Finally, this study concludes that the AI implementation in e-commerce is making online shopping experience is more significant. It is suggested that AI tools

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used to be more user friendly and a customized tools for websites should be introduced in e-commerce which will take the shopping experience to another level.

Limitations of the study : The sample size for the present study was 200 only. It could not be more than 200 due to time constraints as the sample size was confined to the residents of Hyderabad city. The responses received could not be completely be judged as appropriate as the filling of the answers must've been the result of misinformation or hastening. Only 8 tools were focused in the present study is also another limitation of this study.

Scope for Further Research : Further research can be conducted to capture more of the AI tools that are used in online shopping and to focus on rural areas were e-commerce adoption is involved. More research on customer views and suggestions could improve the businesses in applying in e-commerce and provide a platform that reaches a wide range of people for the conduct of the study. Future implications can be discussed as well to provide insight into what changes are bringing in the field of e-commerce.

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A STUDY ON PUBLIC POLICY ACTS FOR THE IMPLEMENTATION OF INTELLECTUAL PROPERTY RIGHTS

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ABSTRACT
Intellectual Property and Public Policy are based on the knowledge skill and economy's emphasis on creativity and innovation. Even though India has a lot of skill and creative energy, there is not a good environment for people to get required access to education, knowledge, and health care. Since India is a TRIPS-compliant nation, the proper sense of equitable and dynamic Intellectual Property regime that has the full potential of harnessing intellectual property for India's economic growth, sociocultural development, and public interest promotion are far-off objectives. The National Intellectual Property Rights Policy stated the public policy initiatives and orientation, but the basic and proper need to establish a robust IP environment in light of the stunning highlighted controversy that is spiralling out of control should not be overemphasized.

The practitioners and academicians to shed light on obscure areas of research. Intellectual property law, technology, cyber law, human rights, access to food and medicine, engineering, biotechnology, and law are just very few of the topics covered in the journal paper. By incorporating most important theoretical and legal aspects of the Indian socio-legal context, the study examines both the aspects of opportunities and the obstacles. For a vibrant nation like India, the outcomes of IP institutional failures are mark of unimaginable, and a pragmatic conclusion is just unthinkable. The study contains revelations that have never been published before and lead to a single impossible and incomprehensible truth: that it is the cure-all for public policy problems. Despite this, unquestionably an incredible collection foretells healthy debates about knowledge management. The policies of IP laws and institutions examined in order to fine-tune India's strategy for IP law reform in the public policy paradigm.

Keywords-Public policy, Intellectual property rights, Institutions and policymakers

INTRODUCTION
Intellectual Property Rights originated during the Renaissance in Italy in the 13th century. With their implementation, an individual was able to protect and earn money from their invention. Soon, this system of patents and copyrights spread across Europe. By the 19th century, it became widely recognized across industrialized countries that allowing the inventor ownership of literary, artistic, creative or scientific works stimulated further innovation. The result was a massive economic growth, in which intellectual property rights played an important role.

The World Intellectual Property Organization classifies the following to be protected as **intellectual property rights**:

- Trademarks including service marks, designations and commercial names
- Inventions
- Industrial designs
- Original creations in industrial, artistic, scientific or literary fields. These include discoveries, works, musical compositions, and performances.

Further, the Agreement on Trade Related **Intellectual Property Rights** (TRIPS) was negotiated by the World Trade Organization and was implemented with effect from January 1, 1995. It is the most comprehensive and exhaustive agreement of its kind till date. Most countries of the world are signatories to this agreement.

TRIPS Agreement protects the following areas:
- Trademarks and service marks
- Industrial designs
- Copyrights and similar rights
- Geographical indications which specify the origin
- Trade secrets
- Design layout of assimilated circuits
- Test data
- Patents including protection of new plant varieties

INTELLECTUAL PROPERTY RIGHTS SYSTEM IN INDIA

India is a TRIPS Agreement compliant country. In recent decades, a number of laws have been passed or amended to bring them on par with world protections. Some of these laws are:
- Patents Act, 1970
- Indian Trademarks Act, 1999
- Indian Copyright Act, 1957
- New Designs Act, 2000
- Geographical Indications of Goods (Registration & Protection) Act, 1999
- Protection of Layouts for Integrated Circuits Act, 2000
- Protection of Plant Varieties and Farmers Rights Act, 2001
- Biodiversity Act, 2002

PATENTS

After three separate amendments - the latest in 2005 - this law offers international level protection. Some of the latest inventions protected under its ambit are those related to the pharmaceutical, chemical, and food industries.

TRADEMARKS

Although an Act in this regard existed from 1958, a new Act was passed in 1999 to make it TRIPS-compliant. Today, Indian **trademark registrations** enjoy the full protection of Indian law.

COPYRIGHTS

The existing Act was amended several times, the last being in the year 2000. Today, it protects communication channels of telecasting and broadcasting as well as emerging software.

DESIGNS

This piece of legislation is fulfilling its purpose on a global scale. It conforms to international trends in design administration and commercial and technical details.

GEOGRAPHICAL INDICATIONS

India's biological diversity has allowed it to enjoy some of the rarest biological resources in the world. The Geographical Indications of Goods (Registration & Protection) Act,

1999 was implemented in 2003. It mandatorily requires the source of biological material employed in the invention to be disclosed.

PLANT VARIETIES

To protect and sustain the most crucial economic sector i.e. agriculture, the Protection of Plant Varieties and Farmers Act, 2001 was enacted. It promotes the development of new varieties as well as conservation of existing ones. Till date, 114 crops and their variants have been registered for protection. The initiative has also allowed for availability of better seed quality for farmers.

India announced its first National IPR policy in 2016. Today, the portfolios of Patents, Designs, Trademarks, Copyright, Geographical Indications, and Semiconductor Integrated Circuits Layout Design all fall under the Department for Promotion of Industry and Internal Trade (DPIIT). Under DPIIT, the Cell for IPR Promotion and Management is tasked with implementing India's National IPR Policy. It spearheads the Indian government's efforts to streamline IP processes, increase IP awareness, promote commercialization, and enhance enforcement.

Over the past five years, the Indian government has taken positive steps to strengthen its IPR regime, such as efforts to modernize its IP offices; increase manpower, use IT and technology in e-filing of applications; deliver certificates of grant and registration of patents and trademarks in a digital format. Reduce the number of trademarks forms; use video conferencing for hearing of IP applications; create expedited examination procedures; and spread awareness on IP issues.

DPIIT, in association with the Federation of Indian Chambers of Commerce and Industry, launched an IPR enforcement toolkit to aid police with handling IP crimes, in particular counterfeiting and piracy. The Maharashtra Cyber Digital Crime Unit was established in August 2017 as a public-private partnership to enable industry to work directly with state police to combat digital piracy. The Unit serves as a potential model for digital enforcement that other Indian states can emulate and replicate.

The Ministry of Education's Innovation Cell has also taken steps to foster innovation and promote IP literacy and awareness in classrooms across the country.

U.S. GOVERNMENT ENGAGEMENT

Engagement with India on IPR continues, primarily through the U.S.-India Trade Policy Forum's Working Group on Intellectual Property, which restarted in June 2021 after a gap of nearly three years. Under the Forum, working-level engagements between the United States and India have also been positive and focus on helping India develop a more transparent, predictable, and reliable enforcement environment. Further, the United States and India continue to actively engage across various platforms, such as the U.S.-India IP Dialogue, and routinely through bilateral interactions on specific IP issues. In addition, the United States maintains positive working relationships with Indian customs, police and judiciary officials, as well as with industry representatives to discuss ways to strengthen India's important enforcement ecosystem.

To further bilateral engagement on intellectual property matters, in December 2020, the United States Patent and Trademark Office and DPIIT signed a Memorandum of Understanding relating to IP technical cooperation mechanisms and the promotion of IP, which is guided by a biennial work plan.

LEGISLATIVE CLIMATE

While India has laws covering almost all types of intellectual property rights and enforcement procedures, the legislative process is often lengthy and uncertain, and the same issues can

remain pending for many years. This can create uncertainty for industries and complicate their strategic IP enforcement decisions.

The Commercial Courts Act, enacted in 2015 and amended in 2018, was established to help reduce delays and increase expertise in judicial IP matters. However, to date only a limited number of courts have benefited under the Act. Rights holders report jurisdictional challenges have reduced the effectiveness of the commercial courts, and inadequate resources for staffing and training continue.

Pharmaceutical and agrochemical products can be patented in India. The Protection of Plant Varieties and Farmers' Rights Act, 2001, protect plant varieties. However, Indian law does not protect against unfair commercial use, nor against the unauthorized disclosure of undisclosed test or other data submitted to the Indian government during the application for market approval of pharmaceutical or agrochemical products.

The Designs Act allows for the registration of industrial designs. The current Designs Rules detail classification of designs, largely to conform to international standards, and are intended to address the proliferation of design-related activities. India's Semiconductor Integrated Circuits Layout Design Act is based on standards developed by the World Intellectual Property Organization; however, the law remains inactive due to a lack of implementing procedures as well as lack of interest in filings.

A June 2018 amendment to the Intellectual Property Rights (Imported Goods) Enforcement Rules, 2007, removed patents from the scope of customs protection. Accordingly, the new customs recordation system permits owners of trademarks, designs, copyrights, and geographical indications to record their IPR with Indian customs authorities and seek enforcement actions for any related counterfeit activity. Customs officers have ex-officio authority to suspend the clearance of suspect imported goods they believe are counterfeits and subject them to examination, seizure, and destruction, though rights holders may have to bear these costs. In addition, the goods may subsequently be released if rights holders do not comply with the recordable requirements.

Protection and enforcement of trade secrets is challenging, as there are no civil or criminal laws in India that specifically address their protection. While India relies on contract law to provide some trade secret protection, this approach is effective only in situations in which a trade secret owner and a party accused of misappropriation have a contractual relationship. Criminal penalties are not expressly available for trade secret misappropriation in India, civil remedies are reportedly difficult to obtain, and often do not have a deterring effect.

India does not provide data protection for the registration of agricultural products. Despite previous attempts to introduce data protection provisions into the Pesticides Management Bill, the pending bill, introduced in 2020, does not provide for data protection for the registration of new pesticides.

Released in June 2021, the proposed Cinematograph (Amendment) Bill contains provisions criminalizing illicit camcording and proposes to enhance penalties against piracy. Unfortunately, the draft bill also creates new concerns for right holders by proposing to apply a broad set of exceptions from the Copyright Act to anti-camcording activities.

In June 2021, India's Department Related Parliamentary Standing Committee on Commerce presented its 161st Review of the Intellectual Property Rights Regime in India Report. The Report emphasizes that the IPR regime should comply with international agreements, rules and norms, and be compatible with those of other nations and foreign entities. While many of the recommendations in the report, such as those relating to trade secrets protection, IP enforcement, and dedicated IP benches at the High Courts, are welcomed, some recommendations, such as those relating to compulsory licenses and statutory licensing for online broadcasting, raise serious concerns and are regarded as problematic for IP rights holders.

In August 2021, the Ministry of Health and Family Welfare launched efforts to frame the new Drugs, Cosmetics, and Medical Devices law to replace the existing Drugs and Cosmetics Act, 1940, by setting up an eight-member expert committee headed by the Drugs Controller General of India (DCGI).

On data protection, a Joint Parliamentary committee released recommendations in December 2021 for a new bill entitled the Data Protection Bill, 2021, that could have undermined important IP protections and stifled innovation, particularly in view of India's outdated and insufficient legal framework for protecting trade secrets. The bill was scrapped in August 2022, though a future bill is set to be introduced within a new legal framework covering data privacy in India.

In December 2021, the Indian government referred the Biological Diversity (Amendment) Bill, 2021 to a Joint Parliamentary Committee for review. The bill seeks to facilitate fast-tracking research and the patent application process; the transfer of research results while utilizing biological resources available in India; decriminalization of certain provisions; and bringing more foreign investments in the chain of biological resources, including research, patent, and commercial utilization.

REGULATORY CLIMATE AND HURDLES

Despite several positive developments, there are also many regulatory hurdles and challenges that affect the commercialization of IP in India. For instance, the interpretation and application of patent law can be unpredictable and inconsistent, particularly in important areas such as determining the scope of patentable subject matter, pre-grant opposition proceedings, and provisions governing the granting of compulsory licenses.

In 2016 and 2017, the Patents Rules and the Trademarks Rules were revised, adopting strict timelines to dispose of cases, streamline examinations, and reduce certain filing fees to incentivize start-up activity. In 2019, the Patents (Amendment) Rules further expanded the categories of applicants eligible for expedited examination of their patent applications. The 2017 examination guidelines for Computer Related Inventions removed all examples of what can and cannot be patentable, deferring to the patent examiner's discretion and raising concerns about the consistency of patentability decisions. In September 2021, the Indian government notified the Patents (Amendment) Rules, 2021, extending the benefit of fee reduction for patent application filings to all recognized educational institutions, including foreign institutions.

India's Copyright (Amendment) Rules, 2021, became effective in March 2021. These rules introduced a host of changes regarding copyright societies, including their registration, management, and functions.

PHARMACEUTICAL AND MEDICAL DEVICES

The lack of coordination between DPIIT and the Central Drugs Standard Control Organization through either patent linkages or an effective notification system invites abusive infringing activities, which compromises the ability of innovative industries to effectively commercialize and enforce their IPR in India. Liberal price controls, coupled with the potential abusive use of procedures such as pre-grant and post-grant opposition proceedings, further complicate an effective IPR regime for the pharmaceutical and medical device industries.

In April 2017, the Ministry of Health and Family Welfare removed the requirement for companies to inform whether a new drug is under patent at the time of filing for a manufacturing license. This is viewed as a regressive step and goes against India's National IPR Policy, which calls for better central and state coordination on IP issues. India still lacks

a system for notifying interested parties of marketing approvals for follow-on pharmaceuticals, which would allow for the early resolution of potential patent disputes.

The threat of price controls for patented pharmaceuticals continues to concern rights holders. The National Pharmaceutical Pricing Authority previously made efforts to invoke emergency provisions to issue price control orders to fix prices for a number of non-scheduled drugs, including patented drugs. The 2015 National List of Essential Medicines included several patented drugs. The List is currently under revision again, and the threat of patented drugs being added to the list remains a significant concern. There are also strong concerns over the unpredictable and opaque application and implementation of the Trade Margin Rationalization formula for price monitoring of the non-scheduled market, including for patented drugs. In January 2019, the Department of Pharmaceuticals amended its 2013 Drugs (Prices Control) Order to exempt manufacturers producing a new drug patented in India from price controls for five years from commencement of their commercial marketing of the drug in India. While this is viewed as a positive development, serious concerns remain over its implementation or potential dilution. Industry continues to seek clarity from Department of Pharmaceuticals on how the amendment is to be implemented.

In the pharmaceutical sector, the absence of clear guidance in implementing Section 3(d) of the Indian Patents Act has restricted patent-eligible subject matter in a way that fails to incentivize innovation by hindering the development of improvements to benefit Indian patients.

In December 2020, the Department of Pharmaceuticals issued guidelines for implementation of the provisions of the 2017 Public Procurement Order, specifying a minimum of 80 percent local component requirement for a Class I local supplier and 50 percent to qualify as a Class II local supplier. The guidelines effectively disqualify non-local bidders from Indian government tenders.

In October 2021, the Department of Pharmaceuticals under the Ministry of Chemicals and Fertilizers sought comments on the Draft Policy to "Catalyze Research & Development and Innovation in the Pharma-MedTech Sector in India." The Draft Policy outlines the adoption of linkages between industry and academia (like that of the United States' Bayh-Dole Act) and IP offices or technology transfer offices in academic institutions, industries, and incubation centres.

TECHNOLOGY, BRAND, AND INTELLECTUAL PROPERTY LICENSING
In 2018, the Indian government formed an inter-ministerial group to investigate reinstating royalty caps for all technology collaborations and brand licensing, limiting the amount of foreign exchange that can leave the country. If implemented, such caps would negatively affect all sectors of the economy in which a company licenses its brand name or enters a technical collaboration. Prior to 2009, India had a similar provision, but it was abandoned in favour of attracting higher levels of foreign investment.

India generally has adequate copyright laws, barring some exceptions. A July 2021 Parliamentary Committee report recommended an amendment to the Copyright Act to extend statutory licensing to include internet and digital broadcasters works. DPIIT has taken this recommendation under consideration, which has deeply concerned companies in the music, entertainment, and creative industries. Amending the Copyright Act to permit statutory licensing for interactive transmissions would be inconsistent with India's obligations under relevant international treaties and would have severe implications for rights holders that make their content available online. The lack of predictability around this issue, along with the expansive granting of licenses under Chapter VI of the Indian Copyright Act and overly broad exceptions for certain uses, have raised concerns about the strength of copyright protection in India and complicated the functioning of the market for music licensing. India's commitment

at the United States–India Trade Policy Forum in November 2021 to comply with the World Intellectual Property Organization Internet Treaties was a positive step, though respective amendments to bring India's Copyright Act into alignment with international best practices has not yet been made.

The Indian Patents Rules require Form 27 to be filed annually by patentees and licensees on the details of their commercial activities for all their patents in force in India. While the annual requirement was initially created to ensure that patentees are working their inventions in India, the form may be hindering innovation. In October 2020, revisions to Form 27 improved the situation, though it still places significant risks and undue burden on rights holders and may compromise their confidential business information and strategies. In addition, failing to comply with Form 27 requirements can create grounds for seeking a compulsory license and could lead to loss of patent, substantial penalties, and imprisonment.

ENFORCEMENT CLIMATE

The Intellectual Property Appellate Board (IPAB) was abolished in 2021, transferring jurisdiction to adjudicate appeals over patents, trademarks, copyrights, and other IPR matters to the High Courts. India's decision to abolish the IPAB and redirect matters to the courts has created uncertainty around adjudication of IP cases and the setting of copyright royalty rates.

In July 2021, the Delhi High Court created a dedicated Intellectual Property Division (IPD) to hear IPR matters, including those previously before the IPAB. The Delhi High Court recently nominated three Judges to exclusively function as the IPD, and in February 2022, the Court notified its comprehensive rules for the IPD. At the same time, the Court notified its rules governing patent suits. The April 2022 Parliamentary Committee Report recommended that, the Indian government encourage High Courts across the country to follow suit and establish their own IPDs.

In 2021, India continued to take steps against websites with pirated content. Despite positive steps taken in online copyright enforcements, such as "dynamic injunctions" for repeat offenders, copyright holders continue to report high levels of piracy, particularly online and through commercial broadcasts. This includes unauthorized file sharing of videogames, signal theft by cable operators, commercial scale photocopying, unauthorized reprints of academic books, and circumvention of Technology Protection Measures.

While there has been some progress, weak enforcement of IP by the courts and police, a lack of familiarity with investigative techniques, and the absence of a centralized IP enforcement agency, combined with a failure to coordinate actions on both the national and state level, threaten to undercut progress.

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EFFICIENT BIOCOAGULANT *Azardicta Indica* BARK POWDER FOR ARSENIC (III) REMOVAL IN THE SOLUTION PHASE

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ABSTRACT
This study aims to remove arsenic from groundwater by employing a series of batch studies on *Azardicta Indica* bark powder that vary in terms of physic-chemical factors such as contact time, dose, pH, initial arsenic content, and temperature. The rate of arsenic absorption decreased as it moved farther inside the biosorbent particles from its initial quick pace. At a pH of 4.0-6.0 and a dosage of 1.5 gm, the impact of contact duration on arsenic biosorption was investigated for 30 minutes.As the initial arsenic concentration rises, the proportion of arsenic biosorption decreases because mass transfer between the solute and solution interface is impeded at higher concentrations. Through the assessment of the biosorbent's mass transfer coefficients, the experimental outcomes were accurately documented in terms of Freundlich and to some degree Temkin isotherms with values of R_2 0.998 and 0.956, respectively.
Keywords: Neem Bark Powder, Biosorption, Biosorbent, Isotherms, Kinetics,Thermodynamics.
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INTRODUCTION
Arsenic is considered the "King of Poisons" and is extremely dangerous for human health in many parts of the world. West Bengal, India, and Bangladesh both have contaminated regions with greater arsenic concentrations.[1] There is more than 10 µg/L of arsenic in the water. High levels of arsenic were discovered in soil samples from Kukatpally, Hyderabad, according to recent research released by scientists from the NGRI in Hyderabad.[2] Arsenic in the soil should be 0.11 mg/kg, according to US Environmental Protection Agency rules, however, the soil in Kukatpally had 0.7 mg/kg of arsenic. Arsenic metal slowly leaks into groundwater due to the region's numerous businesses. The main industries that release arsenic into the environment are agriculture and the copper, lead, and zinc sectors. The majority of the inorganic forms of arsenic found in groundwater are trivalent and pentavalent arsenate. As(III) is far more hazardous and soluble in groundwater than As(V) is. Significantly increasing the risk of cancer[3], infertility, miscarriages in women, heart issues, brain damage, and DNA damage is possible when consuming water contaminated with inorganic arsenic. Removing the hazardous inorganic arsenic from surface groundwater requires the use of purification methods, such as pre-oxidation of As(III) to As(V), to successfully eradicate arsenic.Every conventional filtering technique has pros and cons, including oxidation-precipitation, coagulation-flocculation filtration, ion exchange, reverse osmosis, nano-filtration, and biosorption.[4-6] Because of its simplicity, ability to produce little sludge and capacity for regeneration, biosorption is the most dependable and economical technique for treating groundwater when all of the aforementioned approaches' shortcomings are taken into account. The price of the biosorbent determines the entire cost of the biosorption process. NBP was selected as the biosorbent for this investigation because neem bark powder extracts arsenic more effectively.

EXPERIMENTAL
Material and Methods
Following a two-day sun drying period, distilled water was used to remove any remaining dust and dirt particles from the neem bark that had been gathered from a woodcutter in Hyderabad. The fractions were kept apart in labeled, airtight plastic containers for later usage after the bark powder was sieved using sift

to a particle size of 195 mesh.[6] By enabling the biosorbent (Neembark powder) to enter the effluent more quickly and deeply, the tiny particle size promotes biosorption.[7] Based on the number of sites on the biosorbent material, their accessibility and chemical state, and the binding strength between sites and metal, neem bark powder's characterization and effectiveness in aiding the binding mechanism onto biomass[8-11] will be discovered. Preliminary screening investigations revealed that neem bark powder removed arsenic with 93% efficiency. Neem bark powder was selected for the arsenic biosorption batch experiment based on the aforementioned factors.

General Procedure
By dissolving an adequate amount of arsenic in 1000ml of stock solution, a stock solution of As(III)(1.32g/1000ml) was prepared. The stock solution was further diluted with distilled water for the batch experiment to achieve the required arsenic concentrations, which ranged from 10μg/L to 80 μg/L, which were first created. The biomass was extracted from the sample solutions by filtration, and the concentration of arsenic was measured in the filtrate. A spectrophotometer was used to determine the amount of residual arsenic that remained after the biosorption procedure. The effects of temperature, pH, arsenic concentration, contact time, and biosorbent dosage were all considered in the experiment.

Detection Method
Tannin and lignin are among the organic components found in neem bark, which is based on cellulose (Table-1). To identify the functional groups, FTIR analyses were carried out in the 4000-600 nm range. The FTIR spectra of *A. Indica* showed the presence of carboxylic acid, amine, amino, amide, and sulfate groups in addition to the functional group and surface charge[12], which catalyzed the mechanism of metal binding on Neem bark in the arsenic biosorption process.

Table-1: Properties and Functional Groups of Neem Bark Powder

S.No.	Properties	Values	Functional Groups Before Biosorption	Classification
1.	Surface Area	21.1 cm^2	C-H	Alkene
2.	Porosity	195 mesh	C=C	Alkyne
3.	Ash content	11.50%	C-O	Primary Alcohol
4.	pH	6.0	N-H	Alcohol
5.	Bulk density	0.525 mg/m^2	N-H	Amine salt
6.	Volatility	79.08%		
7.	Carbon	40%		
8.	Hydrogen	3.2%		
9.	Nitrogen	0.54%		

RESULTS AND DISCUSSION

Agitation Time
Because biosorption depends on contact time, a batch bio adsorption experiment was conducted at various intervals using 1.0 gm of neem bark powder as a biosorbent. The biosorption time is the amount of time needed for the concentration of arsenic metal to achieve equilibrium. Kinetic investigations indicate that there are two modes of biosorption: slow intracellular biosorption and fast surface biosorption.[13-15] The experiment's findings indicated that increasing the agitation period increases the elimination of arsenic's efficiency. It required 10 to 30 minutes for there to be a stronger surface binding due to the attraction of arsenic ions toward active functional groups on the adsorbent's surface, or the equilibrium shown in Fig.-1. Additionally, the research data revealed that arsenic ions were moved from the outside to the inside, slowing biosorption.[16] The ideal amount of time for communication to enable the next step was therefore thirty minutes.

Impact of Porosity and Dosage of Biosorbent
Higher doses and smaller particle sizes led to the most efficient elimination of arsenic. This was probably because there were a lot of sorption sites and a big surface area, which allowed for the most efficient removal of arsenic. Both[17,18] found a tight influence: the stronger the metal removal quality, the smaller

the particle size. Biosorbent competitively controlled biosorption potential at lower dosages.[19] Figure-2 illustrates the remarkable arsenic-eradication efficiency of neem bark powder at 1.5 gm biosorbent dosage and 195 mesh particle porosity. Up to a certain point, the amount of biosorbent utilized directly affects how much arsenic is extracted from aqueous solutions; after that, the rate decreases. Decline occurs when the dosage of the biosorbent is increased because the electrostatic contact on the binding sites between cells is broken. The effects of neem bark powder on the biosorption of heavy metals, particularly zinc, were similar.[20,21]

Impact of Porosity and Dosage of Biosorbent

One of the most important variables influencing arsenic biosorption on neem bark powder is pH. This variable generates the charge density on the biosorbent surface as well as the arsenic species.[22] In the pH range of 6.0–9.0, Fig.-3 illustrates the best arsenic biosorption, with an ideal adsorbent dose of 1.5 gm/50μg/L.The strong arsenic biosorption percentage was sixty percent at pH 6.0. After pH 9.0, biosorption could not proceed due to the precipitation of As(OH)2.[23] The impact of pH on the removal of As (III) can be inferred from the surface charge on the adsorbent content. Because of the biosorbent surface's positive charge at low pH 4.0, positively charged arsenic cations may find it more difficult to approach. This suggests that protons may compete with arsenic ions for ligands (-COOH, -NH$_2$), which would reduce metal-ion interaction and lower the percentage of arsenic removal.[24]Higher pH levels promote metal adsorption because of a reduction in electrostatic repulsion, which lowers the positive charge density of protons on sorption sites. Previous researchers have noted similar things.[24,25] The dissociation of various functional groups included in neem bark tan in particles may facilitate the creation of metal complexes, which in turn may be the cause of the biosorption of arsenic (III) ions on the surface of neem bark through an ion-exchange mechanism based on surface complex formation. This idea is summarized as follows:[26]

$$As^{n+}+m[RO7(OH)11]\leftrightarrow As[RO7(OH)9(O^-)2]m^{n-m}+mH^+$$

Where -RO7(OH)11=acidic portion of the bark surface, Asn+=arsenic ion with n+ charge, R denotes the matrix portion of the biosorbent and mH+=number of protons generated. A higher pH can promote improved metal ion biosorption because of the condensation reaction that occurs between the sorbent bearing the –OH groups and the hydrolysis product of sorbate ions.[26,27] Consequently, it can infer that anion-mediated arsenic biosorption on neem bark powder is most likely the cause of complexation, and the combined defect of site binding biosorption is involved in the exchangeprocess. As(III) chemical species (oxyanions) and the amount of hydroxyl groups on the surface of neem bark powder may decrease when pH rises.

The Impact of As(III) Concentration

As arsenic concentrations climb from 10μg/L to 80μg/L, 90% arsenic removal is achieved at 41.2μg/L at the ideal circumstances of 1.5 g of biosorbent and 6.0pH, as illustrated in Fig.-4. The coherence of biosorption (surface saturation) is dependent on the initial concentration of arsenic ions. Arsenic ions are rapidly absorbed by biosorption sites at low concentrations, however, at high concentrations, intraparticle diffusion causes low-level diffusion of arsenic metal ions to the surface of the biosorbent.[28] Adsorption of the arsenic metal ions was easier at initial (lower) concentrations because the impedance of mass transfer between the solid and solution was controlled.[29] Arsenic elimination would not be significantly impacted by an increase in arsenic content since the sorptive sites cannot handle the excess. Arsenic ion concentration. Similar outcomes were obtained by copper biosorption on Cinnamomum camphor leaf powder.[30] Lignin cellulose plant fibers, which have a lot of nitrogenous, hydroxyl, and carboxylic groups, may bind metal ions in neem bark when in an aqueous solution.

Temperature-Dependent Profile of Biosorption

Neem bark powder and different quantities of arsenic solution were used in the Arsenic biosorption procedure, which was conducted at different temperatures. In this investigation, as temperatures and concentrations rose, so did the degree of biosorption.

Due to the increased sorption sites at high temperatures, which facilitate the efficient uptake of arsenic metal ions with greater interface interactions between arsenic ions and different functional groups present in neem bark powder via bioaccumulation, as shown in Fig.-5, temperature had a greater effect on the percentage removal.
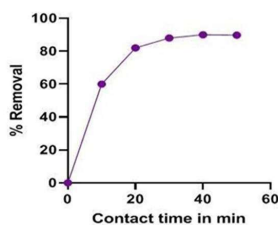
Figure 1: Rate of agitation time for the Arsenic Ren
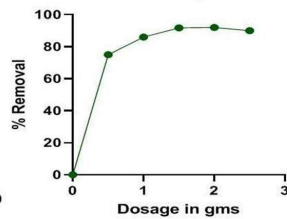
Figure 2: Effect of Dosage on the Arsenic Removal
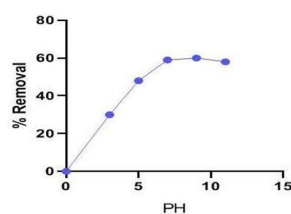
Figure 3: The Influence of initial pH
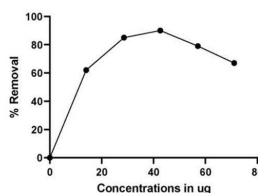
Figure 4: The Effect of Concentration

Langmuir, Freundlich, and Temkin Biosorption Isotherms

It was common practice to investigate the relationship between sorbed and aqueous concentrations at equilibrium in the temperature range of 0ºC to 80ºC using the Langmuir, Freundlich, and Temkin biosorption isotherm models. Biosorption isotherms provide the solute concentration for the solution at equilibrium Ce as well as the mass of the solute absorbed per unit mass of biosorbent qe. R_2 values were computed to determine which biosorption isotherm model fit the data the best.

Langmuir Model

An isothermal survey was conducted using a varied initial concentration, optimum biomass of 1.5 gm, and pH of 6.0 in order to collect data from biosorption tests. The Langmuir model did not linearize to the extent that would have indicated that, despite higher R_2 values as shown in Table-2, the biomass of neem bark was not able to adsorb arsenic ions. Langmuir concluded that the trials' apparent standardized, monolayer adsorption was not the case, and he was unable to provide a plausible explanation for the arsenic biosorption with neem bark powder.

Freundlich Isotherm

The plot of Freundlich (Fig.-6) log qe vs log Ce and its linear equation was modified to the arsenic biosorption in order to identify the interaction of metal ions with biomass.[31] This adaptation accounts for the high magnitude of k_f, $1/n$, and R_2 values in Table-3, demonstrating the strong biosorption capability of neem bark powder. The heterogeneity of the sorbent surface aligned with the Freundlich model. These results showed that this model is appropriate for the biosorption of arsenic on powdered neem bark.

Temkin Model

The interaction of As(III) on the surface of neem bark powder is shown in linear form (Fig.-7) with equal adsorption energies, and the R_2 values in Table-4 are above 0.92. The paper states that all of the molecules in the layer experienced a linear rise in heat of adsorption. This model can also explain arsenic metal biosorption because of its good match. These three models suggest that the biosorption energy of metal binding sites is dependent on the occupied sites nearby. Consequently, it seemed that neem bark powder's biosorption of As(III) ions involved a multilayer, interactive, or multiple-site form binding process.[32]

Kinetic Sorption

Kinetic sorption investigates the reciprocal activity between the biosorbent and adsorbate using kinetic models. The mass transfer as well as the physical and chemical characteristics of the sorbent determine the biosorption process. The expected values derived from the models' and experimental data's conformance were indicated by correlation coefficients (R_2). The pseudo-second-order kinetic equation of As^{+3} connecting qe and k_2 allows for the prediction of the time-dependent accumulation's progress using kinetic parameters.

Figure 5: The Effect of Temperature on Removal | Figure 6: Linear plot of Freundlich for Arsenic biosorption | Figure 7: Linear plot of Temkin for Arsenic biosorption
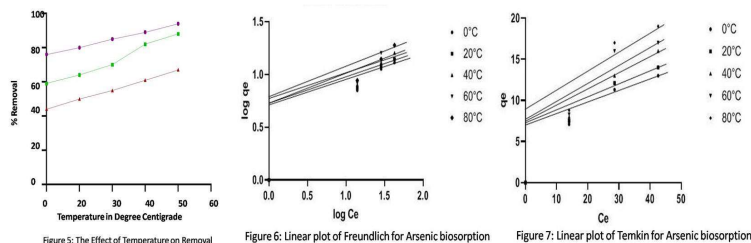
Table-2: Biosorption Isotherm Constant and Statistical Comparison Values of Arsenic Biosorption by Neem Bark Powder

S.No.	Parameters	Langmuir Adsorption Isotherm				
		Temperature ^{0}C				
		0	20	40	60	80
1.	R^2	0.997	0.995	0.989	0.885	0.862
	ASS	0.527	0.525	0.483	0.460	0.419
	Q_0	-0.0070	-0.0073	-0.0070	-0.006	-0.006
	b_L	0.595	0.628	0.662	0.707	0.727
		Freundlich Adsorption Isotherm				
2.	ASS	0.001	0.000	0.000	0.000	0.000
	Log k_f	0.530	0.600	0.615	0.634	0.697
	l/n	0.075	0.017	0.048	0.016	0.016
	b_T	0.222	0.225	0.185	0.351	0.154
		Temkin Adsorption Isotherm				
3.	R^2	0.869	0.989	0.987	0.986	0.981
	ASS	0.067	0.005	0.006	0.006	0.009
	a_T	0.158	0.240	0.282	0.305	0.330
	b_T	0.959	1.436	0.486	0.568	0.678

Table-3: Kinetic Parameters for Biosorption of Arsenic by Neem Bark Powder

S.No.	Parameters	Arsenic Concentration (10 µg/L)	Arsenic Concentration (20 µg/L)	Arsenic Concentration (30 µg/L	Arsenic Concentration (40 µg/L)	Arsenic concentration (50 µg/L)
		Pseudo first order kinetic model				
1.	R^2	0.931	0.902	0.885	0.838	0.887
	ASS	0.007	0.013	0.017	0.028	0.016
	K_1	0.011	0.009	0.007	0.004	0.004
		Pseudo second order kinetic model				
2.	R^2	0.954	0.955	0.959	0.990	0.950
	ASS	0.004	0.004	0.003	0.000	0.004
	K_2	0.320	0.372	0.461	0.415	1.100
		Elovich model				
3.	R^2	0.986	0.921	0.985	0.986	0.942
	ASS	0.006	0.009	0.000	0.000	0.005
	α	-10.28	-9.553	-8.625	-5.329	-6.620
	β	21.17	19.24	16.95	11.58	12.12

		Intraparticle diffusion model				
4.	R^2	0.980	0.953	0.979	0.936	0.929
	ASS	0.001	0.004	0.001	0.007	0.008
	k_{id}	-1.841	-1.696	-1.510	-0.922	-1.165
	I	16.37	14.70	12.74	8.925	8.927

Table-4:Thermodynamic Parameters of Arsenic Biosorption by Neem Bark Powder

S.No.	Temperature	ΔG (KJ/mol)	ΔS (KJ/mol)	ΔH (KJ/mol)
1.	273	-54.47	17.14	- 0.054
2.	293	-56.02		
3.	313	-52.04		
4.	333	-52.60		
5.	353	-46.95		

Equation of Pseudo-First-Order Kinetics

In their wide use of the metal ion adsorption method, Lagergren and Sven produced good findings in their metal adsorption investigations. Ho, Y.S. (1995). Since the equation for the Lagergren plot of log (qe-qt) vs t (Fig.-8) did not provide the linear shape displayed in Fig.-8, it was not possible to quantify the amount of arsenic biosorbent attainment. The R_2 and k_1 values derived from the plot are quite small in Table-4. The fact that the computed value of qe differs from the experimental value of qe suggests that this model was unable to determine qe.

Equation of Pseudo-Second Order Kinetics

Several authors have also suggested that, under certain conditions, second-order kinetics may provide insight into the relationship between biosorbate and biosorbent.[33-36] The study found that the greatest match for the data from this examination was achieved by applying a pseudo-second-order kinetic equation. As (III) biosorption activation energy can be measured by evaluating rate constants at all concentrations, and the experimental data fit well to the pseudo-second-order kinetic with strong correlation coefficients (R_2 0.954-0.990) from Table-5 and linear map (Fig.-9). Since there was no consideration of the external mass transfer obstruction, the computed qe value is consistent with one experiment. It can be inferred from these results that the biosorption of arsenic and other heavy metals followed a pseudo-second-order kinetic.
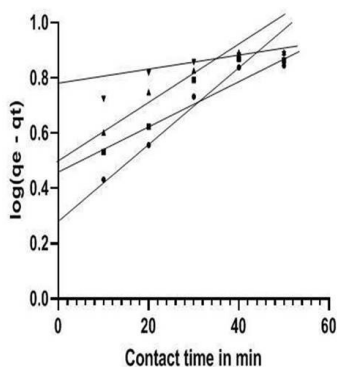
Figure 8: Lagergren plot of Arsenic biosorption
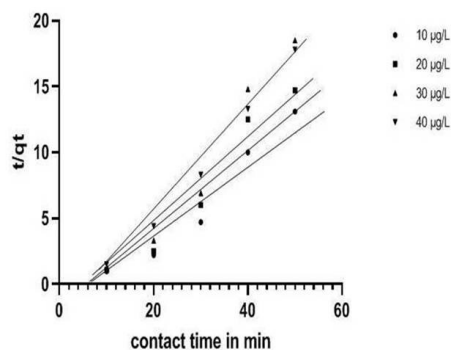
Figure 9: Pseudo second order kinetic biosorption

Table-5: Equilibrium Parameter RL Values at Different Concentrations and Temperature

S.No.	Temperature	Concentration of Arsenic (µg/L) and R_L values		
	(°C)	10µg/L	30µg/L	50µg/L
01.	0	0.1007	0.033	0.200
02.	20	0.1007	0.033	0.200
03.	40	0.1007	0.033	0.200
04.	60	0.1006	0.033	0.200
05.	80	0.1006	0.033	0.200

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Elovich Model
The initial adsorption rate in the Elovich equation and the adsorption constant of the model are connected to the adsorption energy.[37]The energetic heterogeneity of the adsorption sites is a crucial component of this model that was considered for the investigation.[38]This is how the Elovich equation works:

$$(dq_t/dt) = \alpha exp(-\beta q)_t$$

Researchers are encouraged by the Elovich equation to explore the kinetics of pollutant adsorption in natural biosorbents and to comprehend the optimum behavior of data. Understanding reaction mechanisms like solute transport in solution or interphase and surface activation and deactivation is further aided by this equation. It also considers abnormalities in the data that other sophisticated equations have missed.[39] The linearized graphic seen in Fig.-10 was not generated by the Elovich equation. Hence, this model could not be used to demonstrate.
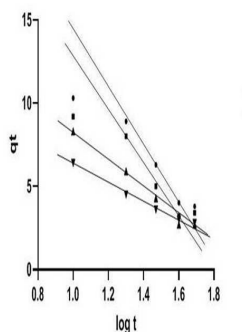
Figure 10: Elovich model for the Arsenic biosorption   Figure 11: Weber-Morris plot onto study of Arsenic biosorption   Figure 12: Relationship between ln(qe/ce) and qe for Arsenic biosorption
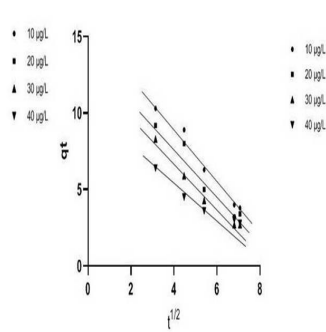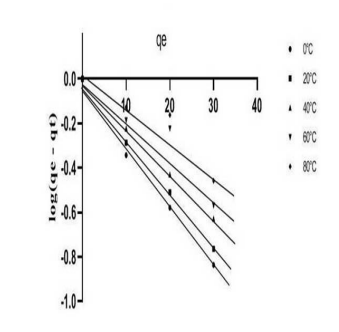
The Weber–Morris Model
Plotting qt vs $t^{1/2}$ yields the rate-limiting step; lines must cross the origin. This model is associated with the diffusion mechanism.[40] The constant k values (slope) derived from the plot with high values[41]determine the great adsorption speed. However, the rate of arsenic biosorption was sluggish due to the low k values in the sample.In the sample, lines did not pass through the origin (Fig.-11), suggesting that biosorption was not the stage that limited the rate and was not controlled by intra-particle diffusion.

Thermodynamic Parameters
Using Gibb's energy (ΔGo, k J mol-1), enthalpy (ΔHo, k J mol-1), and entropy (ΔSo, k J mol-1) changes at temperatures of 273,293,313,333, and 353 K, the thermodynamic behavior of arsenic biosorption onto neem bark powder was investigated.[42]With rising temperatures[43](-54.47 to $-46.95 kJmol^{-1}$), the negative and tiny l values of Gibbs free energy for arsenic metal showed that the adsorption process was thermodynamically feasible and impromptu. The biosorption mechanism in this investigation was exothermic, as evidenced by the negative value of ΔHo ($-0.054 kJ mol^{-1}$). This suggests that chemical sorption occurred during the biosorption process. The positive value of entropy ΔSo (17.14 k J mol^{-1}) during arsenic biosorption onto neem bark powder, as depicted in Fig.-12, suggested an increase in randomness at the solid/solution interface.[44]

Equilibrium
The equilibrium parameter, also referred to as the dimensionless constant se parathion factor, is dimensionless. The vital role of Langmuir's isotherms is known as RL.RL can be expressed as follows:[45]

$$R_L = [1/(1+bC_0)]$$

Where Co is bis Langmuir's constant and the starting concentration of the arsenic metal ion As(III) (mg. L^{-1}). The RL shows whether the isotherm is unfavorable (RL > 1), linear (RL = 1), or permanent (RL = 0). The equilibrium parameter for arsenic biosorption at various temperatures and concentrations was reported to be the favorable biosorption process onto neem bark powder.[45, 46]

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Neem Bark Powder SEM Analysis Following Biosorption
An effective tool for examining morphology, texture, pore volume, pore diameter, particle size, and form is the scanning electron microscope (SEM). Neem bark has been shown in earlier studies to be an amorphous substance with a rough texture and surface. SEM tests were performed at different magnifications and widths (500 k, 50 k, 2.0 k, and 1.0 k) to investigate the morphological and behavioral changes of neem bark following biosorption.[47] Figure-13 displays the SEM pictures.
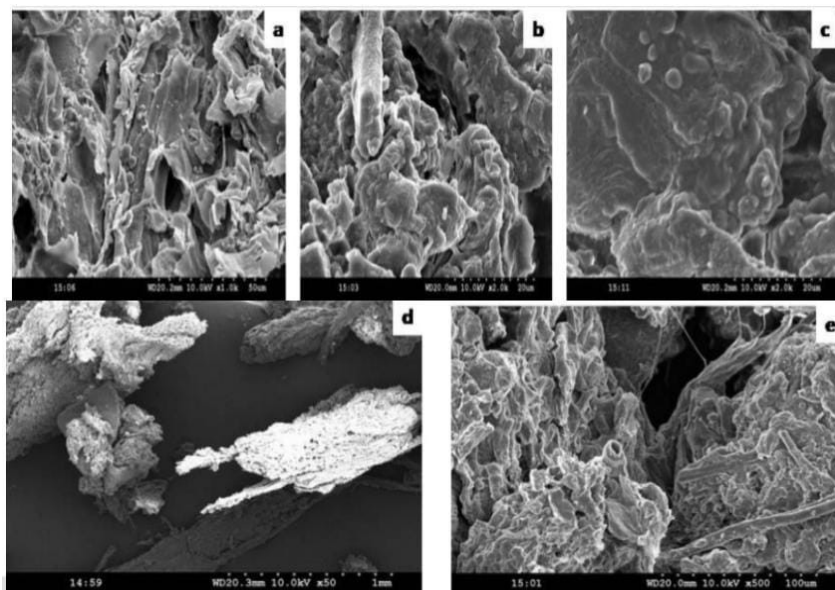
Fig.-13: Scanning Electron Microscopy (SEM) Images after Biosorption

(a),(b)Multi-structured particle aggregation, cavities, aberrations, andk ink scan all be seen on the surface of neem bark. The small molds indicate the biosorption of arsenic ions by the surfaces of neem bark, suggesting the presence of porosity.(c)The rear two distinct phases of arsenic and neem bark are visible. At 2.0 k, there is a decrease in surface heterogeneity with two different images of different widths.Thebiosorptionofarsenicbyploy-molecular/poly-electrolyteandthe behavior of neem bark as a strong biosorbent is confirmed by the surface coverage with particles adhering to the surface. (d)The molecules and the aggregation of arsenic particles at certain parts of the surface determined the biosorbent-biosorbate relationship. (e) The surface appears to be rough because of the cavities and tubular/long rod-shaped particles that are aggregated into normal shapes/mosses.

FTIR Spectra Before and After Adsorption
In Fig.-14, the FTIR spectrum of the biomaterial derived from neem bark displays a broad band between 3550 cm^{-1} and 3250 cm^{-1}, indicating the existence of –NH and –OH vibration strains. The amine groups' C-N stretches peak at 1180 cm^{-1}, whereas the primary and secondary amines' N-H stretches peak at 1690 and 1590 cm^{-1}, respectively. A wavelength of 1300cm^{-1}–1400cm^{-1} indicates the presence of aliphatic carbons, CH2 coupled to double bonds, aromatic compounds, and carbonyls, according to research studies.[48-51] The shift in the peak of the arsenic-loaded biomaterial to 3700 cm^{-1} - 3900 cm^{-1}, or 3907.8 cm^{-1}, 3884 cm^{-1} to 3858.4 cm^{-1}, 3705.5 cm^{-1}, suggests that the -NH and -OH groups are present during the biosorption process. The vibrations/peaks in the 1500–1600 cm^{-1} range show the involvement of the carboxyl group's C–OH, alkyl carbonate groups, and primary secondary amines' –NH stretching. Divergent peak located in the biomaterial's fingerprint regionNeembark's biosorption behavior is improved by the behavior that is seen. Chelation with various functional groups explains neem bark's biosorbent behavior.

XRD Study of Powdered Neem Bark
Figure-15 shows that the XRD diffraction revealed no clearly defined peaks in any region, which is typical of biosorbent materials and indicates amorphous behavior. This behavior has been noted in research on the elimination of chromium and is shown both before and after arsenic ions are absorbed by the surface of neem bark.[52-54] As a result, we can conclude that neem tree bark is an effective biocoagulant for the adsorption of arsenic in solid waste.
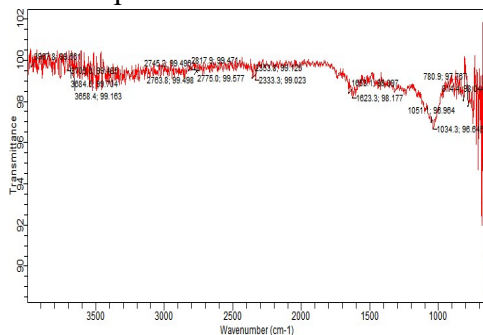
Fig.-14: FTIR image of Neem Bark Powder after Biosorption
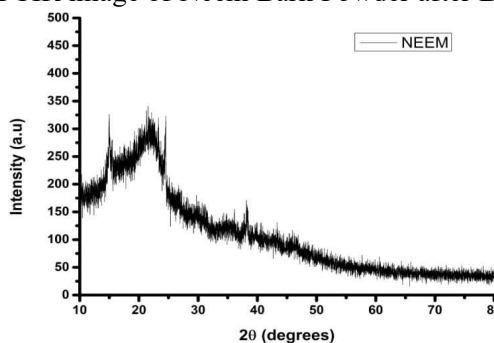
Fig.-15: XRD Image of Neem Bark Powder after Biosorption

CONCLUSION
Batch biosorption experiments were carried out in this study to discard As(III) from aqueous solutions using neem bark as a low-cost, readily available natural biosorbent. Biosorption properties were investigated at various pH levels, initial metal ion concentrations, contact time, and biosorbent dosage levels. The following is a summary of the findings:

• Since the number of adsorption sites increases as the mass of the adsorbent increases, metal ion adsorption increases. Maximum absorption for As (III) for biosorbent was obtained at an adsorbent dose of 1.5g, which may be considered the optimum biosorbent dosage level under the conditions.

• The pH experiments revealed that rivalry of H+ ions with metal ions at low pH values, maximal adsorption at pH 4–6, and precipitation of hydroxyl species onto the adsorbents at higher pH values are the governing factors affecting the biosorption characteristics of allbiosorbents(pH7-11).

• As evidenced by correlation coefficient values, the experimental data were best represented by a pseudo-second-order model(R2). On neem bark, As(III) biosorption follows the Freundlich adsorption isotherm model.

• Thermodynamic parameter studies revealed that As(III)biosorption occurs naturally. With increasing temperatures, the Gibbs free energy (Go)values for As(III) in neem bark powder increase from-54.47to-46.95KJmol[-1].

• Biosorption was found to be exothermic with an enthalpy of -0.054 k Jmol-1 and an improvement in randomness at the solute-solution interface with an entropy of 17.14kJmol[-1].

• The functional groups C–O,C-H, and C–N are responsible for metal binding, according to

Fourier Transform In infraredspectrophotometer (FT-IR) studies. Hence, *AZARDICTA INDICA*bark can be used as an important natural biosorbent for the economical treatment of wastewater containing As(III).

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CONFLICT OF INTERESTS

The authors have no conflicts to declare.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID IDs, given below:

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Communication

Electromicrofluidic Device for Interference-Free Rapid Antibiotic Susceptibility Testing of *Escherichia coli* from Real Samples

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Abstract: Antimicrobial resistance (AMR) is a global health threat, progressively emerging as a significant public health issue. Therefore, an antibiotic susceptibility study is a powerful method for combating antimicrobial resistance. Antibiotic susceptibility study collectively helps in evaluating both genotypic and phenotypic resistance. However, current traditional antibiotic susceptibility study methods are time-consuming, laborious, and expensive. Hence, there is a pressing need to develop simple, rapid, miniature, and affordable devices to prevent antimicrobial resistance. Herein, a miniaturized, user-friendly device for the electrochemical antibiotic susceptibility study of *Escherichia coli* (*E. coli*) has been developed. In contrast to the traditional methods, the designed device has the rapid sensing ability to screen different antibiotics simultaneously, reducing the overall time of diagnosis. Screen-printed electrodes with integrated miniaturized reservoirs with a thermostat were developed. The designed device proffers simultaneous incubator-free culturing and detects antibiotic susceptibility within 6 h, seven times faster than the conventional method. Four antibiotics, namely amoxicillin–clavulanic acid, ciprofloxacin, ofloxacin, and cefpodoxime, were tested against *E. coli*. Tap water and synthetic urine samples were also tested for antibiotic susceptibility. The results show that the device could be used for antibiotic resistance susceptibility testing against *E. coli* with four antibiotics within six hours. The developed rapid, low-cost, user-friendly device will aid in antibiotic screening applications, enable the patient to receive the appropriate treatment, and help to lower the risk of anti-microbial resistance.

Keywords: antibiotic susceptibility testing; microfluidic; antimicrobial resistance; *E. coli*; multidrug resistance; minimum inhibitory concentration

1. Introduction

The accurate and early detection of microbial infection, followed by appropriate treatment via antibiotic administration, is pivotal in reducing the fatality and severity of the disease in a patient [1,2]. Antibiotics are effective against bacterial infection, by killing the bacteria or inhibiting its growth [3]. Alexander Fleming, a physics scientist, accidentally discovered the first antibiotic, penicillin, to treat bacterial infection. That simple discovery saved millions of lives over decades [4]. Since then, several antibiotics have been prepared and discovered over the years. However, with time, these microorganisms become resistant to drugs. Antimicrobial resistance arises when microbes do not have a more extended response to the medicine, making the infection harder to treat [5]. Therefore, with minimalistic symptoms and disease onset, it is crucial to identify the microorganism and

the antibiotic effective against it. An antimicrobial resistance (AMR) test is often conducted; AMR shows the type and quantity of antibiotic working against the microorganism [6].

Various pathogens, like bacteria, fungi, viruses, and parasites, cause infection and form resistance [7]. Among these, bacterial and viral infections are more prevalent [8]. Pneumonia, diarrhea, and urinary tract infections are the most pervasive bacterial illnesses caused by *Escherichia coli* [9]. *E. coli* is the most known bacterium that causes multidrug resistance [10]. Improper use of antibiotics, multiple illnesses, and prolonged stays in the hospital are critical risk factors for *E. coli* multidrug resistance [11]. Therefore, knowing the antibiotic effect, dosage, and duration before use is essential. Antibiotic susceptibility testing (AST) helps identify the pathogen and the most effective antibiotic against it [12,13]. AST provides information on selecting antibiotics and evaluates the minimum inhibitory concentration. It detects both phenotype and genotype resistance. Genotype is classified based on the presence or absence of a resistant gene, and phenotype is found without the gene mutation. Different techniques are available; among them, disk diffusion is the gold standard for AST, as is quick to execute, can identify many antibiotics in a single test, and allows for a wide range of antibiotic choices. Still, it takes time and cannot provide minimum inhibitory concentration values. Another method is broth dilution [14], which is straightforward, legitimate, and easily accessible but demands more supplies of reagents and introduces more room for error. Moreover, these traditional AST approaches are time-consuming and labor-intensive, requiring skilled laboratory set-up and bulky instrumentation [15]. Often, a time frame of 4–5 days is reportedly needed to study the resistance clinically. Owing to this, the infection increases, and sometimes delays can even be fatal [16]. Hence, developing rapid techniques for measuring antibiotic effectiveness will improve global health and decrease mortality [17]. In this context, miniaturized and microfluidics-based devices provide possible solutions [18,19]. Microfluidic-based devices offer multiple advantages of reduced assay time, low cost, simple operation, and increased testing efficacy [20,21]. However, some microfluidic devices need high resolution. A microfluidic device has recently been designed to separate microbial cells using a ferrohydrodynamic approach. However, the developed device is complex and requires more attention to the environmental effect on fluid flow inside the channel [22]. Hence, microfluidic integrated with electrochemical sensing further improves the detection efficacy and increases the simplicity and sensitivity of detection [23,24].

The present study is an extension of our previous work [25]. Herein, we developed a rapid, sensitive, miniaturized electrochemical device for simultaneous culturing, detection, and antibiotic susceptibility study [26,27]. Here, *E. coli* was used as a model microbe for testing the device. A screen-printed electrode system modified with graphitized mesoporous carbon (GMC) was used for testing [28]. GMC is a high surface area carbon material that helps sensitively detect *E. coli* [29,30]. The microfluidic channel was designed and integrated with screen-printed electrodes. The in-house laser-induced graphene (LIG) heater was fabricated to incubate bacterial culture. Various antibiotics were screened by checking the minimum inhibitory zone, and the one with a more significant inhibition zone was selected for susceptibility testing. Different antibiotic concentrations were prepared, and efficacy was checked using the electrochemical cyclic voltammetry (CV) method. The specificity of antibiotics towards *E. coli* was validated using *Streptococcus pneumoniae*, *Pseudomonas aeruginosa*, and *Shewanella putrefaciens* bacteria. The real sample analysis was done using artificial urine and water samples. The obtained results were further validated with the conventional broth dilution method. To the extent feasible, this is a benchmarking prototype study that has yet to be explored further. The strategy with further optimizations can also be used for other microorganisms in real-time. Figure 1 shows the mechanism of action of different antibiotics to prevent bacterial growth.

Figure 1. Schematic representation of the mechanism of action of antibacterial drugs.

2. Experimental Method

2.1. Materials

Luria broth and Luria agar were procured from Thermo Fisher Scientific, Delphi, India. Potassium chloride, carbon ink, glass slides (75 × 50 mm), ammonium phosphate, sodium sulfate, ammonium diphosphate, magnesium chloride, calcium chloride, creatinine, and urea were purchased from Sigma Aldrich, Ltd. (Burlington, MA, USA). *E. coli* culture was acquired from the Biological Science Department, BITS Pilani Hyderabad campus. Clavam 625 (amoxicillin and clavulanic acid), Zenflox 200 (ofloxacin), Monocef-O 200 (cefpodoxime), Cifran 500 (ciprofloxacin), and Azee-500 (azithromycin) were purchased from a local medical store. Polydimethylsiloxane (PDMS) was purchased from Delta Silicon, Mumbai, India. A CO_2 laser (VLS 3.20) was procured from Universal Laser Systems, Scottsdale, AZ, USA.

2.2. Development of Three-Electrode System and Microfluidic Device

A three-electrode system was fabricated using the screen-printing technique. The design of the requisite dimension was first drawn on SolidWorks software. A polyvinyl chloride (PVC) sheet was attached to a glass side (75 × 50 mm), and the laser was scribed over the PVC sheet to prepare the mask. Carbon ink was laid down over the obtained mask with the help of a squeeze and kept in the oven for 30 min at 60 °C. The PVC sheet was removed after drying, and the screen-printed electrodes were obtained [31]. Figure 2 depicts a detailed schematic of the fabrication process.

Figure 2. Schematic for the development of a three-electrode system using the screen-printing technique.

A mold ($2 \times 1.4 \times 17$ mm^3) was prepared on an acrylic sheet to develop the microfluidic device. To create a PDMS mixture, epoxy and curing agent were mixed in a 10:1 ratio and degassed for 30 min to remove oxygen bubbles. Following this, PDMS was run over the mold and baked for an hour at 60 °C. Post-curing, the reservoir was cut from the mold and bonded over the three-electrode system using the plasma bonding method. The developed

microfluidic device integrated with the laser-induced graphene (LIG) heater is shown in Figure 3. The details of the fabrication scheme for screen-printed electrodes, microfluidic device fabrication, and its integration, as well as how to prepare bacteria samples, were covered in greater depth in our previous research [25].

Figure 3. (**A**) A miniaturized device integrated with (**B**) a laser-induced graphene (LIG) heater provides temperature, and copper tape provides electrical contacts connected to the voltage regulator. (**C**) The LIG heater captured by a thermal camera after heating while providing a voltage of 2.5 V.

2.3. Fabrication of LIG Heater

For the fabrication of the LIG heater, a polyamide sheet of the required dimension of 25×25 mm was initially pasted onto a glass slide surface using double-sided tape. The CO_2 laser (VLS 3.60) was exposed on the polyimide sheet with power and speed of 6.5% and 4.5% to obtain laser-induced graphene [32]. After engraving, the obtained thickness was 50 μm. Electrical contacts were provided on the fabricated LIG film using copper tape and silver ink. The thermal factor was calibrated earlier by varying the potential and noting the temperature. A temperature of 37 °C was maintained by applying a potential of 2.5 V. A thermal camera was used to keep track of the achieved temperature. Figure 3C shows the temperature of the LIG heater, which was maintained at 37 ± 10 °C.

2.4. Effect of Antibiotic on E. coli

Electrochemical analysis was used to determine the effect of antibiotics on bacterial growth. A Potentiostat (CHI 1030E) was utilized to record the electrochemical response. A three-electrode setup was employed, with a reference electrode of Ag/AgCl, a working electrode of GMC, and a counter electrode of plan carbon ink.

2.5. Evaluation of Real Samples

The real samples used for analysis were synthetic urine and tap water [14]. The synthetic urine was prepared by adding all dried components to sterile water. Normal urine is a mixture of organic compounds such as urea, creatinine, and uric acid and inorganic substances like ammonia, sulfates, chloride, and phosphates. The composition of prepared synthetic urine is provided in Table 1.

Table 1. Composition of synthetic urine.

Components	Quantity (mg/L)
Potassium Chloride (KCl)	2000
Sodium Sulfate (Na_2SO_4)	2000
Ammonium Phosphate (($NH_4)_3PO_4$)	850
Ammonium Diphosphate (($NH_4)_3PO_4$)	850
Calcium Chloride ($CaCl_2$)	250
Magnesium Chloride ($MgCl_2$)	500
Urea (CH_4N_2O)	600
Creatinine ($C_4H_7N_3O$)	50

3. Results and Discussion

3.1. Off-Chip Minimum Inhibitory Concentration (MIC) Measurement

The MIC describes the resistance or susceptibility of the particular bacteria toward valuable antibiotics. The model microorganism used was *E. coli* (DH5α strain) for MIC calculation. An agar plate containing Luria–Bertani (LB) broth was used to sustain *E. coli* cells. A colony of *E. coli* cells was removed from the agar plate and suspended in 5 mL of LB liquid media. Overnight at 37 °C, the cells were cultured in the medium on a shaker at 200 rpm. After that, fresh LB medium was used to dilute the cell suspension until it reached an optical density of 0.01 at 600 nm.

The antibiotic stock solution (1 mg/mL) of cefpodoxime, ofloxacin, amoxicillin, clavulanic acid, and ciprofloxacin was prepared in sterile water. Several concentrations, ranging from 100 to 500 g/mL, were prepared from the stock solution, and the MIC was measured using a disk diffusion approach. The LB agar media was prepared and poured into a Petri plate. After solidifying the agar gel, the bacterial culture was spread over the plate. Using sterile forceps, an antibiotic disk of cefpodoxime, ofloxacin, amoxicillin, clavulanic acid, and ciprofloxacin was applied to the plate and incubated for 12 to 24 h at 37 °C. The minimum inhibition zone formed at the edge of the antibiotic disk was calculated. Figure 4 shows the disk diffusion method for MIC calculation. The distance from the antibiotic disk to the inhibition area for every antibiotic was calculated. The one that covered more inhibition zones, i.e., ciprofloxacin, was selected for a real sample and interference study.

Figure 4. Disk diffusion method for calculation of minimum inhibitory concentration.

3.2. Electrochemical Detection of Antibiotic Effect over the Bacterial Growth

To carry out the electrochemical investigation of bacterial growth inhibition, 100 µg/mL antibiotic concentration of cefpodoxime, amoxicillin and clavulanic acid, ciprofloxacin, and ofloxacin with bacterial culture media was injected into four miniaturized reservoirs through the inlet. Before the analysis, the reservoir was washed with 0.1 M PBS to prevent cross-contamination. The LIG heater was used to incubate the bacterial culture throughout the experiment, which is necessary for bacterial growth. The electrochemical detection was carried out using CV for 6 h, and after every hour, the response was recorded. Figures 5 and 6 show the electrochemical reactions of the control sample (without antibiotic) and four antibiotics, and their respective calibration plots are given in Figure 7. According to the minimum inhibition zone study, out of four antibiotics, ciprofloxacin was more effective toward *E. coli* bacterial inhibition. The bacterial concentration would decline in the device with increased time and a constant temperature. In Figure 6, the current value increases with incubation time because of antibiotics on bacterial growth. Usually, when the bacteria grow, they accumulate over the electrode surface and block ion flow, decreasing the peak current value, which we can see in Figure 5 without antibiotic response. The antibiotic helps to increase the transfer of ions in the media, which was blocked by the growth of bacteria, as shown in Figure 6 [32].

(a)   (b)

Figure 5. A cyclic voltammetric graph of bacterial culture without antibiotics (**a**) and its respective calibration plot (**b**).

Figure 6. Cyclic voltammetric graphs of four antibiotics at concentrations of 100 µg/mL. The experiment was performed in the microfluidic device for 6 h, and the response was recorded at intervals every 1 h. (**A**) Ofloxacin, (**B**) cefpodoxime, (**C**) ciprofloxacin, (**D**) amoxicillin and clavulanic acid.

Figure 7. Calibration plot of four antibiotics was performed in the microfluidic device for 6 h. (**A**) Ofloxacin, (**B**) cefpodoxime, (**C**) ciprofloxacin, (**D**) amoxicillin and clavulanic acid.

3.3. Interference Study

The specificity of the Clavam antibiotic toward *E. coli* was checked in the developed microfluidic device. Four variants, namely *Streptococcus*, *Shewanella*, *Pseudomonas*, and *E. coli*, were tested with Clavam antibiotic. The first *E. coli* with Clavam antibiotic was injected into the device, and CV response was recorded, Figure 8a. *Pseudomonas*, *Streptococcus*, and *Shewanella* were then added into the same device, and the CV response was measured. A similar current histogram for *E. coli* and an additional variant mixed with *E. coli* is shown in Figure 8b. The apparent difference in the inhibition values for *E. coli* and other bacterial species confirms that ciprofloxacin did not affect *Shewanella putrefaciens*, *Pseudomonas aeruginosa*, and *Streptococcus pneumoniae* [25]. The efficiency of ciprofloxacin against different pathogens was negligible or less than 10%, indicating that it is solely effective against *E. coli* species or that the developed sensor is specific toward *E. coli* species.

Figure 8. CV graph for specificity study of antibiotics (Ant) toward *E. coli*, *Pseudomonas aeruginosa* (PA), *Streptococcus pneumoniae* (Stp), and *Shewanella putrefaciens* (Sch). CV graph responses (**a**) and respective total current plot variation (**b**).

3.4. Antibiotic Susceptibility Testing Using Synthetic Urine

A urine sample is mainly used for examining a medical condition. However, obtaining the same quality urine for many illness detections takes time and effort. Hence, synthetic urine is used for experimentation purposes [33]. Along with this, water pollution due to microorganisms is also a significant issue that causes waterborne diseases. Therefore, there is a critical need to detect the microbial pollution of water [34]. Consequently, urine and water samples were selected for real sample analysis. Before testing, synthetic urine and tap water were autoclaved to avoid any microbial contamination.

E. coli culture was inoculated into the synthetic urine and tap water before being injected into the device. The electrochemical response was checked for 7 h at hourly intervals. The CV response of a water sample and synthetic urine is shown in Figure 9. The rise in current under the influence of antibiotics was observed [35]. As time increases, the current values also increase because the antibiotic decreases the growth of bacteria. The volume of ions in the urine increases the flow of ions, increasing the current value. This signifies the effect of antibiotics on the growth of bacteria.

Figure 9. CV graph for real sample analysis performed in the microfluidic device for 7 h in (**A**) tap water and (**B**) synthetic urine.

4. Conclusions

This study developed a label-free, simple, cost-effective, miniaturized electrochemical microfluidic device to diagnose microbial resistance and bacterial infection rapidly. The designed device demonstrated remarkable sensitivity toward *E. coli* and detected the antibiotic susceptibility within a concise 6-h timeframe. As part of our methodology, a three-electrode system was added to our miniaturized platform, with the working electrode modified with GMC, the reference electrode using Ag/AgCl, and the counter electrode composed of bare carbon ink. Electrochemical detection was performed using cyclic voltammetry, which enabled accurate measurements. The working electrode was modified with GMC to improve sensor performance and increase precision. Four antibiotics of the same concentration were tested in the susceptibility study, and the interference of the antibiotic toward *E. coli* was detected. Further antibiotic susceptibility study was performed in both artificial urine and water samples, ensuring the versatility and robustness of our device's performance. The obtained outcomes were validated with the conventional approach, confirming the reliability of our findings. To address the pressing demand for rapid and accurate antibiotic susceptibility testing, integration with Cyber-Physical System (CPS) augmented techniques, like data mining and machine learning, with essential automation will aid in diagnosing antibiotic susceptibility rapidly. These technologies will advance the diagnostic process and enhance its accuracy. Moreover, as bacterial resistance to conventional treatments continues to rise, there is a critical need for technologies that accurately distinguish between resistant, susceptible, and persistent bacterial strains. These advancements pave the way for precision medicine, yielding optimal diagnostic results in the ever-evolving landscape of bacterial infections.

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Fully 3D Printed Miniaturized Electrochemical Platform With Plug-and-Play Graphitized Electrodes: Exhaustively Validated for Dopamine Sensing

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ABSTRACT Globally, a contemporary trend is towards the realization of sustainable, eco-friendly, miniaturized, and cost-effective sensors. This work focuses on developing a plug-and-play device using inexpensive and biodegradable UV resin fed 3D printing stereolithography (SLA) to produce miniaturized microfluidic platforms for electrochemical sensing. The device consists of three compartments designed to accommodate the 3-electrodes according to the need. SLA 3D printing technique solves these restrictions, making sensors reliable, repeatable, and durable. For electrochemical detection at the point of need or as a lab-on-chip (LoC) platform with minimal sample volume, this work attempts to construct a flexible as well as non-flexible microelectrode setup. The analytical capability of the platform is examined by quantifying nanomolar levels of dopamine in human body fluids. Chronoamperometry and cyclic voltammetry on surface-treated graphene-poly lactic acid (g-PLA) microelectrodes modified with gold nanoparticles are carried out utilizing a handheld potentiostat. The designed device has a linear range of 0.1 to 120 nM with limit of detection and limit of quantification of 0.083 and 0.27 nM, respectively. Various electrode characterizations, including scanning electron microscopy, energy-dispersive X-ray spectroscopy, and electrochemical impedance spectroscopy are carried out. The developed device is finally tested for real-time analysis on human blood and serum samples.

INDEX TERMS Stereolithography, 3D printing, plug-and-play microelectrodes, electrochemical sensing, microfluidics, point of need (pon), handheld portable potentiostat.

I. INTRODUCTION

The diminutive size of analytical apparatus is receiving a considerable attention in recent times. In comparison to conventional analytical systems, customized analytical equipment offers a multitude of benefits, such as diminished consumption of samples and reagents and refuse generation, thereby reducing the environmental impact of the analysis. Another feature is portability, and which allows to do analyses anywhere, including remote locations [1], [2]. Microfluidics is an interdisciplinary field that combines the disciplines of physics, chemistry, medicine, biology, and tissue engineering to manipulate small sample volumes quickly, enabling the investigation and replication of flow patterns in systems [3]. Microfluidics is crucial for preciseinvestigations of blood flow to replicate biological processes, necessitating the use of three dimensional (3D) geometries made from biocompatible materials [4], [5]. 3D printing, also known as additive manufacturing, is commonly used to create microfluidic

channels due to its benefits: (1) decreased time as well as cost for production, (2) ability to achieve micrometer-scale bare minimum feature size for appropriate dimensions, and (3) unrestricted creation of complex 3D shapes. Complicated 3D microfluidic channels with microelectrodes compartments can be produced using the 3D printing approach without the need for additional processes like casting as well as bonding on a large scale at a reproducible and inexpensive cost [6], [7]. Although layer-by-layer deposition process in 3D printing has its limitations, this technology provides distinct benefits such as expedited prototype, adaptable design, and customization options that may surpass the slower throughput for applications such as microfluidic sensing. As the advancement of 3D printing technology progresses, there will likely be attempts to increase printing speed without compromising on quality. This will contribute to narrowing the gap in throughput compared to traditional batch processes like soft lithography [8].

Common 3D printing methods include stereolithography (SLA) as well as fused deposition modeling (FDM). The product is created by selectively exposing a photocurable liquid resin to light in order to polymerize it. The layers may be carefully solidified and then put on top of each other using firm adherence till the product of choice is formed. SLA-based 3D printing offers high resolution ranging from 25 to 100 μm over FDM, ensuring accurate layer depositions and producing a refined finish on the printed structure [4], [9].Soft lithography involving Polydimethylsiloxane (PDMS) is also been widely employed in the fabrication of microfluidic devices owing to its inert properties, biocompatibility, and ability to transmit light [10]. The fabrication process with PDMS entails skillful execution and underscores the valuable expertise needed to ensure the best possible results [11]. The concluding stage in the assembly process of the microfluidic chip involves utilizing plasma-assisted bonding to join the cured PDMS material onto a glass slide [12], [13]. This is then followed by the incorporation of inlet and outlet ports, along with tubing connections. The intrinsic hydrophobicity of PDMS can be temporarily overcome by plasma exposure, but this solution won't be long-lasting. Additionally, it is the ability to absorb minuscule molecules, which might result in surface contamination. This is a significant issue in the field of biological investigations. When it comes to acids, bases, and solvents, PDMS isn't very compatible. The integrity of the microfluidic device and the experimental conditions could be compromised if these substances cause PDMS to swell or dissolve. Water evaporation through PDMS and a lower zeta potential than glass are two further drawbacks [14], [15], [16].

To overcome these limitations, UV resin 3D printing (SLA) is used for the fabrication of microfluidic devices. SLA can produce high-resolution microfluidic structures in both vertical and horizontal directions of the device. When it comes with sensing in microfluidic platforms, electrochemical analysis stands out. It is fully compatible with miniaturization, especially with the fabrication of microdevices and the use of handheld potentiostats. Additionally, it offers satisfactory selectivity and sensitivity through an appropriate selection of

instrumental parameters as well as electrode material [17], [18], [19]. The primary electrodes utilized in electrochemical detection are noble metals, including gold and platinum, as well as carbon-based compounds [20]. Poly lactic acid (PLA) is a thermoplastic polymer that is biodegradable and biocompatible. PLA with carbon-based composites is used in several electrochemical sensors, the incorporation of graphene with PLA filament (g-PLA, a conductive filament) which is commercially available that are used for 3D printing (FDM) technique is shown to increase the conductivity of PLA and are selective towards the dopamine (DA) detection [21]. Commercially marketed conductive filaments have a low graphene weight percentage. One issue in employing 3D printed (FDM) g-PLA electrodes is to guarantee that enough electroactive material remains on their surface. Plasma treatment must be conducted on the 3D printed (FDM) g-PLA filament with low-pressure Oxygen. The oxygen plasma treatment has notably enhanced the conductivity of the g-PLA filament [22], [23].

Metallic nanoparticles (mNPs) have gained prominence as a highly promising material and have been extensively utilized in various domains, including sensing and catalysis, biola-beling as well as optoelectronics, owing to their distinctive properties [24]. Of all the mNPs, gold nanoparticles (AuNPs) have been extensively used in biosensors owing to their high conductivity and catalytic activity. The modification of g-PLA with electrodeposited AuNPs led to improved optical, electronic, and catalytic properties of the electrode. AuNP with Graphene or carbon fiber microelectrodes have been known to selectively determine DA in the presence of Ascorbic Acid (AA) [25]. The utilization of biodegradable photosensitive resins to produce an 3D printed (SLA) microfluidic device platform with three adjustable microelectrode compartments integrated with biocompatible and non-toxic g-PLA modified microelectrodes allows for the development of environmentally friendly and cost-effective sensors. Few of the examples where microfluidic devices is used for the electrochemical detection of DA based on low detection limit and wide linear range are consolidated and presented on Table S1 [26], [27], [28], [29], [30], [31].

The additional categories of electrode types that improve the performance of electrochemical sensing and can be easily connected and used in the developed platform are nanostructured electrodes, exemplified by carbon nanotubes and metal nanoparticles, offer unparalleled sensitivity, facilitating precise analytical detection. Composite electrodes, which seamlessly integrate conductive polymers with carbon materials, provide a harmonious balance of flexibility and stability, ensuring consistent performance across diverse environmental conditions. Screen-Printed Electrodes (SPEs) emerge as economical and adaptable solutions, particularly beneficial in diagnostic scenarios. Biofunctionalized electrodes, tailored with enzyme or aptamer modifications, guarantee specificity in biosensing applications. Surface-modified electrodes, utilizing self-assembled monolayers or plasma treatments, bolster both selectivity and reactivity, enhancing the accuracy of analyte detection. Additionally, the incorporation of

3D-printed and transparent electrodes, alongside magnetically modified variants, widens the scope of electrochemical applications, encompassing realms from medical diagnostics to environmental monitoring. These diverse electrode classes collectively contribute to advancing the capabilities and versatility of the developed sensing platform.

This work proposes a novel, straightforward, and cost-effective electrochemical microfluidic device capable of accommodating three micro electrodes (working electrode (WE), counter electrode (CE), and pseudo-reference electrode (RE)), fabricated on an 3D printed (SLA) substrate. The device, which is constructed from biodegradable material (photocurable liquid resin) featuring compact dimensions and adjustable microcompartments, offers a platform that aligns with the principles of Green and Sustainable Analytical Chemistry. This adaptive sensor exhibited exceptional performance and durability, presenting various possible applications. The device is demonstrated to detect dopamine in human body fluids using surface treated g-PLA modified microelectrodes as a proof of concept.

II. EXPERIMENT

A. CHEMICALS AND APPARATUS

Dopamine Hydrochloride (DA > 98%), Uric Acid (UA, 99%), Ascorbic Acid (AA, 99%), Glucose (Glu, 99%), L-cysteine (L-Cys, 99%), Creatinine (Cre. 99%), Urea, Insulin from bovine pancreas, serotonin hydrochloride, Hypoxanthine (Hpx, 99%) and Tetra chloroauric (III) acid trihydrate 99% ($HAuCl_4.3H_2O$), melanin has been procured from Sigma Aldrich. Sodium Nitrite (NO_2^- 99%) and Potassium Nitrate (NO_3^- 99%) have been procured from SRL Chemicals, Conductive Graphene Composite PLA has been purchased from Black Magic 3D, USA. All the chemicals used are of scientific purity grade. All the electrochemical measurements are carried out using portable potentiostat (Sensit smart , PalmSens BV, The Netherlands), SPE connector (2 mm, PalmSens BV, The Netherlands) and bulk potentiostat (SP-150 BioLogic, France). Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray (EDX) techniques are carried out using Apreo scanning Electron microscope. Vacuum plasma system (CUTE, Femto Science, North Korea) is used for g-PLA surface treatment. For real sample analysis, human blood serum samples from single donor are obtained from Medical center of university campus.

B. FABRICATION AND ACTIVATION OF 3D PRINTED PLUG-AND-PLAY MICROFLUIDIC CASING WITH PLASMA G-PLA MICROELECTRODES

The microfluidic device is fabricated utilizing clear Resin (Form labs,V4, USA), a commercially available resin, employing a cost-effective approach based on 3D printing (SLA) technique. The printer is furnished with X-axis, Y-axis and Z-axis, which are responsible for controlling the positioning of objects on the developing platform as well as operate based on the coordinate system (cartesian). The resolution of the printer
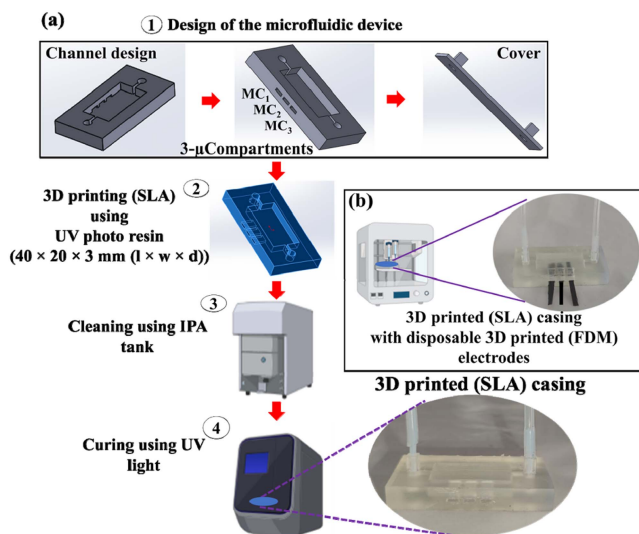
FIGURE 1. (a) Fabrication steps for 3D printed (SLA) microfluidic device casing with three adjustable microelectrode compartments and inlet/outlet ports; (b) 3D printed (SLA) casing with disposable 3D printed (FDM) electrodes.

is limited by the size of the laser spot, whose measurement is of 140 μm in the XY-plane, and the thickness of each layer is 25 μm in the Z- direction. The microfluidic device (rectangular) is of 40 mm in length (l) and 20 mm in width (w) with a channel dimension of length (20 mm) and depth (3 mm, d). The device is initially created using a licensed computer-aided design (CAD) software (AutoCAD, Autodesk, Inc., California, USA) using the above-mentioned dimensions, to create a three-dimensional (3D) model. Furthermore, the device incorporates three adaptable microelectrode compartments (MC_1, MC_2 and MC_3) that facilitate the integration of the 3-electrode into the device. The resulting file is stored in the". stl" file format. The software-Form Labs, is employed to execute layer optimization, resulting in the successful execution of the printing procedure. The additional parts are removed after the printing process and cured. The developed device is cleaned for 15-minute using isopropyl alcohol (IPA) tank and cured at 60 °C for 5 minutes as depicted in the Fig. 1(a).

3D printed (FDM) technique (Fig. 1(b)) is used for the fabrication of g-PLA filament-based electrodes. The first step is to model the 3D desired design of g-PLA micro electrodes using the licensed computer software AutoCAD. The 3 microelectrodes WE, CE and RE are designed as rectangular sheets with dimensions of 20 mm × 3 mm and a thickness (t) of 1 mm as shown in Fig. 2. Then, the filaments are loaded in the printer and proper bed levelling are ensured before printing. The computer designed microelectrodes printing process is facilitated using FDM based 3D printer (Creator pro Flashforge, Zhejiang, China), employing an extrusion temperature of 220 °C and a nozzle speed of 45 mm/s. The bed temperature is set to 60 °C, while the nozzle diameter measured 0.4 mm via the open slicing software FlashPrint 5.0 (FlashForge corporation, China). The surface of printed g-PLA undergoes plasma
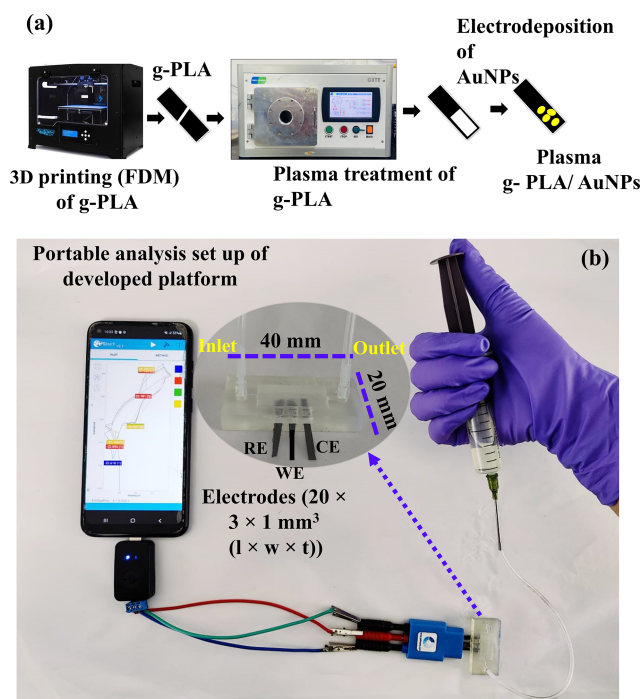
FIGURE 2. (a) Schematic for the surface treatment and synthesis of plasma g-PLA/ AuNPs and its electrochemical investigations; (b) Fully 3D-printed miniaturized electrochemical platform with plug-and-play electrodes.

FIGURE 3. (a) CV response of g-PLA, plasma g-PLA device before and after electrodeposition of AuNPs; (b) Nyquist plots of plasma g-PLA and modified plasma g-PLA at 2V amplitude. Inset: corresponding randles sequence circuit.

treatment to activate it and enhance the materials adhesion capabilities, enabling improved bonding with the materials to be coated. This surface treatment is performed using Vacuum Plasma chamber (Femto Science, Gyeonggido, South Korea) by securely positioning the g-PLA on the sample carrier under a pressure of 1 bar and for a duration of 7 minutes to achieve adhesion as well as long term stability (Fig. 2).

C. SYNTHESIS AND OPTIMIZATION OF GOLD NANOPARTICLES (AUNPS)

The surface treated, plasma g-PLA is used for electrode-position of AuNPs. The electrochemical technique involved the deposition of gold nanoparticles onto the working area of plasma g-PLA by reduction of 16.23 mM $HAuCl_4 \cdot 3H_2O$. Multiple volumes (4, 8, 12, and 16 μL) of $HAuCl_4 \cdot 3H_2O$ solution is deposited over the active region of a plasma-treated g-PLA substrate. This is conducted to establish the ideal volume necessary for effective electrodeposition (Fig. 2(a)). The electro deposition technique is carried out using cyclic voltammetry (CV) with a potential range of -1 to 1 V and a scan rate of 20 mVs^{-1}, using PBS (pH = 7) as an electrolyte for 40 cycles until the reduction peak of Au appeared. Fig. S1. (a) indicates that a volume of 12 μL of $HAuCl_4 \cdot 3H_2O$ shows the best characteristics for effective electrodeposition, as seen by the increased background current. This g-PLA/AuNPs is further used as WE, g-PLA/Ag-AgCl is used as RE and g-PLA alone is used as CE for electrochemical

analysis using a SPE connector [32], portable potentiostat [33] and smartphone as shown in (Fig. 2(b)).

III. RESULTS AND DISCUSSIONS
A. ELECTROCHEMICAL MEASUREMENTS

CV of the electrodeposition of AuNPs have been shown in Fig. S1 (b). The appearance of the oxidation as well as reduction peaks indicate the formation of AuNPs on plasma g-PLA.CV experiments are performed on the fabricated microfluidic device at a scan rate of 20 mVs^{-1} under a pH of 7 using PBS as the electrolyte solution. Fig. 3(a) depicts the CV of g-PLA, plasma g-PLA before and after the electrodeposition. It is evident that the baseline current of the plasma g-PLA/AuNPs in PBS solution is significantly higher compared to that of plasma g-PLA. This can be attributed to the distinctive catalytic and electrical characteristics of AuNPs present on the surface of plasma g-PLA, leading to an enhancement in area of the surface of the modified electrode thereby increasing the conductivity. Electrochemical Impedance spectroscopy (EIS) is an efficient electrochemical analysis tool for evaluating the physical characteristics of an active surface. It provides a reliable estimate of the
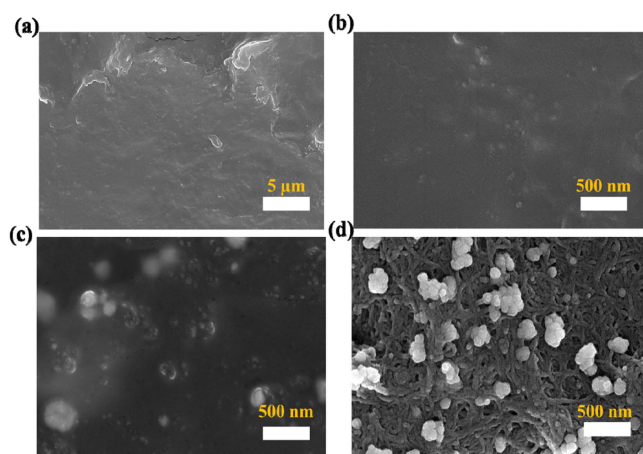
FIGURE 4. SEM morphology and EDAX spectra of (a, b) bare g-PLA, (c) plasma g-PLA, and (d) plasma g-PLA/ AuNPs.

FIGURE 5. Electrochemical oxidation mechanism of dopamine on modified electrode.

charge transfer resistance (R_{ct}), which is mainly driven by the electron transfer process occurring between the electrolyte and the electrodes surface. The diameter of the semicircle obtained in the Nyquist plot is directly proportional to R_{ct} [34] . EIS is performed with a logarithmic frequency range of 1 Hz to 100 kHz and at an amplitude of 2V efficient and accurate characterization. The charge transfer resistance of the plasma PLA is decreased from 1110 Ω to 122 Ω indicating the high conductivity of the AuNPs and its Randles equivalent circuit fit is shown in the Fig. 3(b). Here, R_S refers to the electrolyte solution, R_{ct} represents the resistance to charge transfer resistance, and Z_W denotes the Warburg impedance. This impedance is caused by the movement of electroactive substances from the bulk solution to the surface of the electrode. The capacitance of the electrode surface/solution interface, denoted as C, represents the interfaces capacity to hold charge. It pertains to the formation of a double layer on the surface of the electrode caused by the adsorption of ions from the solution [35].

B. STRUCTURAL AND MORPHOLOGICAL ANALYSIS

Scanning Electron Microscopy (SEM) is used to analyze the morphological behavior in the surface of the electrodes. SEM image of untreated PLA in Fig. 4(a) and (b) displays a uniform composition with soft and smooth surface resulted because of its molecular structure and processing method used by manufacturer [36]. Following the plasma treatment, the surface material exhibits the presence of spots (Fig. 4(b)), which can be attributed to the elimination of impurities from the untreated g-PLA leading in the generation of surface roughness [37]. The spots on the plasma g-PLA have increased after the electrodeposition indicating the formation of AuNPs. The size of the deposited nanoparticles is found to be around 20–50 nm (Fig. 4(c)) which indicates effective deposition which results in increased catalytic activity. The observed phenomenon suggests that the electrodeposition is further enhanced the surface roughness of plasma g-PLA [38]. Energy-dispersive X-ray
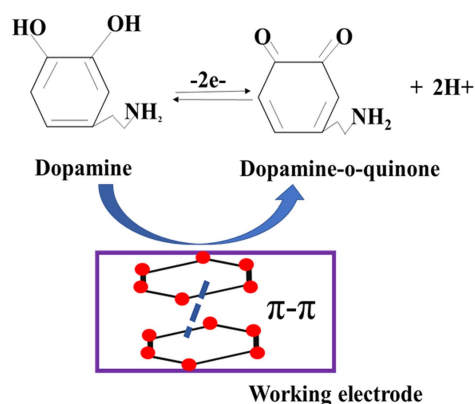
spectroscopy (EDAX) analysis of modified electrodes is listed in Table S2. Enrichment of oxygen is observed after plasma treatment indicating the efficacy of oxygen plasma treatment. The presence of Au spectra indicates the successful formation of AuNPs.

C. EFFECT OF SCAN RATE AND PH

When appropriate electrical voltage is applied to the plasma g-PLA/AuNPs, the compound DA undergoes oxidation to form DA-o-quinone as shown in Fig. 5. This process occurs through the shifting of two electrons as well as two protons. DA can engage in hydrogen bonding and electrostatic interactions with functional groups that are oxygenated on the electrode surface. Furthermore, the interaction between graphene aromatic rings and the DA can be facilitated by $\pi-\pi$ stacking [38], [39]. These combined interactions result in a strong and stable binding of dopamine to the composite material. CV experiments are performed on the fabricated microfluidic device at a scan rate of 20 mVs^{-1} under a pH of 7 using PBS as the electrolyte solution. The measured amount of DA is altered during the experiment and the oxidation potential (E_{pa})is found to be 0.36 V as shown in Fig. 6(a). The impact of scan rate during the process of oxidation of DA with plasma g-PLA/AuNPs is investigated by varying scan rates ranging from 10 mVs^{-1} to 140 mVs^{-1} as depicted in Fig. S2. (a) in PBS (pH = 7) for 0.3 nM of DA. The experimental findings from Fig. 6(b) indicates a linear relationship between the anodic peak current as well as the scan rate, showing an increase in current. A linear correlation is determined between the different scan rates of the anodic current peak, referred to as I_{pa}, (I_{pa} = 0.36x + 4.1). Coefficient of correlation, R^2 is calculated to be 0.994. The results obtained demonstrate that the electrochemical analysis of the plasma g-PLA/ AuNPs integrated microfluidic device is facilitated by diffusion mechanism. The diffusion coefficient can be calculated by Randles Servick equation using the obtained slope 0.36.

$$I_{pa} = \left(2.69 \times 10^5\right).n^{3/2}.A.C.D^{1/2}.\upsilon^{1/2} \tag{1}$$
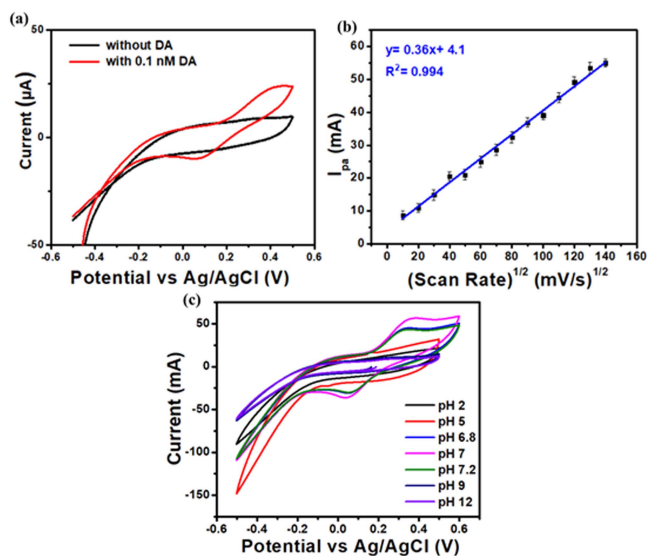
FIGURE 6. (a) CV response with and without DA in PBS (pH = 7) at 20 mVs^{-1}, (b) the peak current as function of square root of scan rate curves, and (c) CV of g-PLA/AuNPs in 0.3 nM of DA at 40 mVs^{-1} for varying pH (25, 6.87, 7.2, 912).

FIGURE 7. (a, b) CV for varying concentration of DA at 20 mVs^{-1} in PBS of pH = 7 and corresponding baseline corrected calibration plot, (c, d) CA response for increasing concentration of DA versus Ag/AgCl in pH = 7 PBS (at E_{pa} = 0.36 V) and corresponding baseline corrected calibration curve.

'I_{pa}' indicates Anodic peak current (the maximum current observed during the forward sweep of a cyclic voltammogram), 'n' indicates number of electrons transferred in the redox reaction., 'A' represents electrode surface area (in cm^2), 'C' indicates Concentration of the electroactive species (in mol/cm^3), 'D' is the diffusion coefficient of the electroactive species (in cm^2/s) and 'υ' is Scan rate (in V/s) [40].

A pH of 2–12 is used to evaluate the pH impact on the mechanism of the DA oxidation at the plasma g-PLA/AuNPs. The electrocatalytic behavior of DA is found to exhibit susceptibility to fluctuations in the pH levels of the electrolyte solution. From Fig. 6(c), it is evident that high peak current (at E_{pa} = 0.36 V) can be attributed to electrochemical anodic oxidation process taking place at a pH value of 7. At this specific pH level of 7, dopamine exhibits enhanced stability and mostly resides in its neutral state. This state of neutrality maximizes its capacity for oxidation, resulting in more distinct and well-defined electrochemical signals. Moreover, the relationship between dopamine along with the electrode surface is more favourable, resulting in improved adsorption as well as electron transfer rates. These combined factors contribute to the observed increase in sensitivity at neutral pH. Hence PBS at pH = 7 is considered suitable for DA detection ((Fig. S2 (b)).

D. ELECTROCHEMICAL DETECTION, INTERFERENCES STUDIES, REPEATABILITY AND REPRODUCIBILITY STUDIES

DA sensing is performed using the CV technique at a scan rate of 20 mV s^{-1} from −0.5 V to +0.5 V in PBS with a pH of 7. The concentration effect as well as the corresponding curve for calibration are illustrated in Fig. 7(a), (b). The current increased with rise in concentration, with a wide linear range of 0.1 nM to 120 nM, a quantification limit of 0.32 nM and a
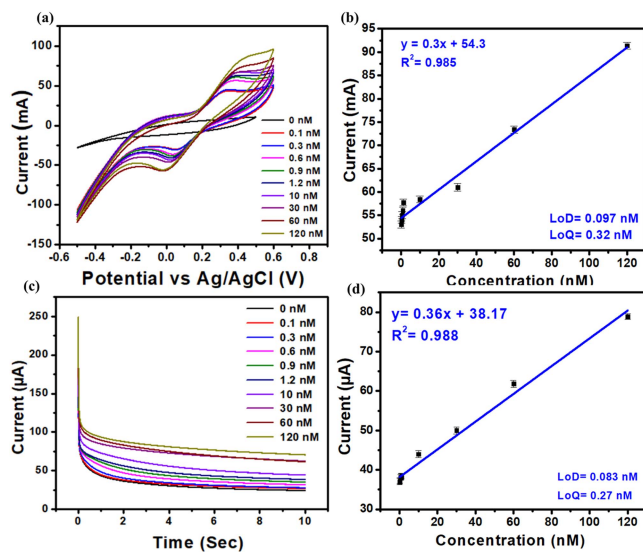
detection limit of 0.097 nM. The interference experiments are performed to validate the electrodes selectivity towards DA, which is a critical parameter for real-time detection in human body fluids. For this, Chronoamperometry (CA) is performed at 0.36 V (Fig. S3 (a)). Along with DA, many other electroactive substances found in the biological samples such as AA, Insulin, serotonin, NO_2^-, NO_3^-, L-Cys, Glu, Cre, Hpx, UA, melanin and cholesterol (Mix 1–11) are sequentially added ((Table S3). CA is carried out using 1 nM of DA and 5 folds of other analytes to maintain the ionic strength of the molecules. The currents obtained from the CA indicate that the sensor is selective towards DA with a standard deviation of 3.3.

The corresponding relative error bar diagram shown in Fig. 8(a) illustrates that the interferent species have a minimal impact on the current changes proving that plasma g-PLA/AuNPs can be used for the selective electrochemical determination of dopamine. Additionally, the concentration effect is assessed at 0.36 V using the CA technique. as illustrated in Fig. 7(c) and (d), a linear range of 0.1 nM to 120 nM is observed for DA (R^2 = 0.987).

The Limit of detection (LoD) as well as Limit of quantification (LoQ) is found to be 0.083 nM and 0.273 nM, respectively. Fig. S3. (b) shows the repeatability of 12 washes of plasma g-PLA/AuNPs. The study compared the CA signals from a 0.3 nM concentration of DA in PBS (pH = 7), it is therefore observed that the g-PLA/AuNPs in detecting dopamine remains relatively stable after multiple washes, but prolonged washing can compromise the robustness of g-PLA attachment to AuNPs due to physical agitation and buffer exposure. Variations in experimental conditions like temperature and agitation intensity during washing may further contribute to degradation of the g-PLA/AuNPs electrode modification and resulted in an acceptable RSD value of 1.7 (Fig. 8(b)). The reproducibility of the plasma g-PLA/AuNPs is assessed

FIGURE 8. Error bar for (a) interference studies, (b) repeatability, and (c) reproducibility.

TABLE 1. Real Sample Validations of Plasma G-PLA/Aunps Microfluidic Device With Human Blood and Serum

Samples	Added (nM)	Found (nM)	Recovery (%)	RSD (%)
Blood	0	0.4	-	2.41
	10	10.5	105	2.53
	50	51	102	3.85
Serum	0	0.35	-	2.75
	10	9.8	98	3.12
	50	52	104	2.86

E. REAL SAMPLE VALIDATIONS

To analyse the applicability of the plasma g-PLA/ AuNPs microfluidic device, real sample analysis is performed using human blood and serum. The blood samples are collected from healthy volunteer. Serum samples are obtained by centrifuging the blood samples at 3500 RPM and stored at sub-zero temperatures until the moment of analysis. CA analysis is performed using the spiking technique. A fixed quantity of DA is added to individual portions, each containing 5 mL of a specific sample. The process of calculating DA recovery is executed utilizing the conventional method of addition. DA is introduced into each sample at different concentrations. The device demonstrated a high recovery rate ranging from 98% to 105%. The results, acquired through conducting three iterations, are presented in Table 1.

IV. CONCLUSION

A first attempt to introduce an innovative, simple, and affordable (2 USD per device platform) electrochemical microfluidic device that can hold three micro electrodes (working, counter, and pseudo-reference) fabricated using 3D printing (SLA) technique. The device is made from biodegradable material (photocurable liquid resin) with compact dimensions and adjustable microcompartments aligning with the principles of UN sustainable development goals (SDGs) and green chemistry (SDG 3-Good Health and Well-being and SDG 12-Sustainable Consumption and Production). This research work also offers the benefit of creating a design that can be interchanged with various types of electrodes, including flexible and non-flexible microelectrodes. This design allows for electrochemical detection as PoN/LoC platform. It is compatible with low sample volumes and can be customized to the users preferred shape and dimension. The sensors quantitative sustainability is evaluated from quantifying DA in human body fluids using modified surface-treated g-PLA electrodes fabricated by 3D printed (FDM) technique. The plasma g-PLA/AuNPs successfully detected DA with an oxidation potential of 0.36 V. The LoD as well as LoQ are found to be 0.083 nM and 0.27 nM respectively. The device is further characterized by repeatability, reproducibility, and stability. The modified electrode is characterized by SEM, EDAX and EIS. Real sample analysis is also been performed on the

by conducting experiments with three sensors developed under similar conditions using CA technique as illustrated in Fig. S3. (c). The device showed a high level of reproducibility, as evidenced by error bar plot in Fig. 8(c). The observed variation of 1.6% between Trial 2 (device 2) and Trial 1 (device 1), and 3.8% between Trial 3 (device 3) and Trial 1 (device 1), falls within an acceptable range for research-grade analysis. These devices were fabricated under conditions aimed at ensuring consistency, yet slight differences in environmental factors like temperature and humidity may have influenced their performance. Such fluctuations can impact the behavior of electrochemical sensing devices, contributing to the slight observed variations in sensitivity among trials.

device which establishes that the plasma g-PLA/ AuNPs integrated microfluidic device can be used for the selective determination of DAto assess its suitability in real-time scenarios specifically by conducting tests using human blood and serum samples for onsite analysis. This developed platform has the capability to detect multiple analytes simultaneously. This can be achieved through additional adjustments and modifications made to the platforms surface for future studies.

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Feedback

Fluctuations of glucose levels in the haemolymph of fresh water Crab *Barytelphusa cunicularis* and its effect on Homeostasis

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ABSTRACT:

Crabs play an important roles in the food web of aquatic and terrestrial ecosystem . . The purpose of this study is to the investigate the mechanism of glucose regulation in crustacean crab Barytelphusa cunicularis. The present datasets were conducted to investigate glucose concentration in haemolymph, energy levels of the crabs when exposed to feeding environments, and stressed starvation during a 45-day culture period.

Hyperglycaemia is a typical response of many aquatic animals to pollutants and stress and in crustaceans increased circulating Crustacean hyperglycaemic hormone (CHH) and hyperglycaemia are reported to result from exposure to several environmental stressors..

Glucose assessment showed a direct relationship between the increase in glucose levels and exposure to stressful environments.

INTRODUCTION:

Crabs are semiterrestial crustaceans and play an important role in the food web of aquatic and terrestrial ecosystem and may serve as indicators of ecological health, particularly in small estuaries where conditions may be strongly correlated to watershed and local factors (Liao SW, Chang WL, Lin SW. Status, 2008) .

Barytelphusa is a genus of freshwater crabs belonging to the family Potamidae. These crabs are primarily found in South and Southeast Asia, inhabiting freshwater habitats such as rivers, streams, and marshes. The genus is characterized by its small to medium-sized crabs, adapted to an aquatic lifestyle.

Barytelphusa cunicularis is a common species of freshwater crab found in India. It is distributed throughout the country from Himachal Pradesh in north to Kerala in south except north east India. (Pati, S.K.; Thackeray, Tejas, June 2018).Key features of this species include a flattened and broad carapace, which helps them navigate through their aquatic environments.The carapace is of a dark chestnut black color, and is nearly smooth. The claws

are of the color of the shell, but the basal joint of the first and the whole of the other legs are much paler-colored, being of a dirty testaceous brown, with very numerous small transverse black marks.(Westwood, J. O.,1835)They possess well-developed walking legs and claws,

which are adapted for both swimming and crawling. These crabs are equipped with gills that allow them to extract oxygen from water, enabling them to live in aquatic habitats. (Diwan, A. D., 1971)

These species are often found in tropical and subtropical regions, where they play crucial roles in aquatic ecosystems. They are omnivorous, feeding on a variety of plant and animal matter, including algae, detritus, small invertebrates, and even small fish. Their presence in freshwater ecosystems contributes to nutrient cycling and helps maintain the balance of the aquatic food web. While *Barytelphusa cunicularis* are well-studied, there is still much to learn about the biology, ecology, and behaviour of these crabs. (Kalki, Yatin, June 2021)

Conservation efforts are important to ensure the protection of their habitats, as freshwater ecosystems worldwide face various threats from human activities and environmental changes. Understanding and preserving the biodiversity within the *Barytelphusa* genus contribute to the overall health and stability of freshwater ecosystems.

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Some of the recognized species in the *Barytelphusa* genus include:

- *Barytelphusa cunicularis*

- *Barytelphusa lugubris*

- *Barytelphusa guerini*

- *Barytelphusa jacquemontii*

- *Barytelphusa pulvinate*

Glucose serves as a crucial blood parameter in physiological investigations, extensively employed to assess responses to stressors across vertebrates and invertebrates alike. Stressors disrupt homeostasis in animals, impacting their fitness and reproductive capabilities. In such instances, mechanisms regulating homeostasis utilize energy stored in various tissues to restore balance (Remage-Healey & Romero, 2000).

Glucose, primarily derived from glycogen conversion, serves as the primary energy source for crustaceans (Full & Herreid II, 1984). Physiological processes requiring Adenosine Triphosphate (ATP) depend on this carbohydrate type.

Consequently, elevated glucose levels are typical in stressful circumstances, making glucose a widely utilized physiological marker in crustacean research.

Strategies of metabolic adaptation to environmental stress in aquatic organisms depend both on the nature and the degree of stress. (Hochachka and Guppy,

1987).In times of stress, hormones and other compounds may be released to trigger the release of stored glucose from tissues. (Webster S.,1996)Handling and alien environment produce only a small increase in blood glucose levels of normal animals.(Dana,1851)

Crustaceans regulate glucose levels in their hemolymph through the crustacean hyperglycemic hormone (CHH), which induces hyperglycemia under stressful conditions. CHH, primarily produced by the X-organ/sinus gland complex in the eyestalks, functions as a neuropeptide promoting the mobilization of glycogen stored in the hepatopancreas (Chung JS, Zmora N, Katayama H, Tsutsui N,2010)

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Various forms of CHH constitute a component of the eyestalk neuropeptide family, alongside the moult inhibiting hormone (MIH) and the gonad inhibiting hormone (GIH), collectively known as the CHH/MIH/GIH family. Synthesized within the X-Organ, a cluster of neuron perikarya situated in the medulla terminalis of the eyestalk, these neuropeptides are transported to and stored in axon terminals, forming a neurohemal organ called the Sinus Gland. They are subsequently released via exocytosis into the hemolymph. The primary role of CHH is to regulate hemolymph sugar levels, although it also plays a role in other functions such as reproduction (Front Endocrinol (Lausanne), 2020).

The present study aims to observe the changes in the haemolymph glucose levels when crabs were exposed to stressful environmental conditions i.e. when the crabs were starved. A total of 25 *Barytelphusa cunicularis* crabs were sampled. The method used was the Benedict's method of assessment of glucose along with the colorimetric assessment of glucose samples for the presence of glucose in extracted samples of Haemolymph.

METHODOLOGY:

1. The crabs were maintained in the laboratory conditions for 10 days prior to
2. the experiment and fed with grass for acclimatization.
3. 25 freshwater crabs *Barytelphusa cunicularis* were taken for the experiment.
4. Hemolymph was extracted from the coxa of the fourth walking leg using 10ml pyrogen-free disposable syringes containing a pre-cooled anticoagulant solution.Anticoagulant solutions were used at a 1:1 hemolymph:anticoagulant ratio .
5. Glucose levels in the haemolymph were determined by colorimetric method.
6. Reagent used: Benedict's reagent
7. Photoelectriccolorimeter 133 for performing the colorimetric analysis for the presence of glucose (set at 540 nm)
8. 5 ml and 10 ml syringes were used to extract haemolymph from the *Barytelphusa cunicularis*

Benedict's Test

- This is a very simple and effective method of the amount of glucose in the haemolymph.
- Principle: $Glucose(R\text{-}CHO) + 2Cu^{+2} + 2H_2O \rightarrow$ Gluconic acid$(R\text{-}COOH) + Cu_2O + 4H^+$ acid$(R\text{-}COOH) + Cu_2O + 4H^+$
- Procedure: 5 ml of Benedict's reagent to three samples of Haemolymph. Boiling the mixture & cool down it, observe changes colour.
- Three different concentrations of haemolymph were taken for the determination of glucose. i.e. 1.0 ml, 1.5 ml and 2.0 ml in three different test tubes.
- 5 ml of Benedict's reagent is added to each test tube with haemolymph.
- The mixture was boiled and cooled down and observed for the changes in colorimeter and then the changes in the colour O.D values were noted.

Fig.1 - Extraction of haemolymph from the crabs

Fig.2 - Reddish colour of sample from indicating presence of

glucose
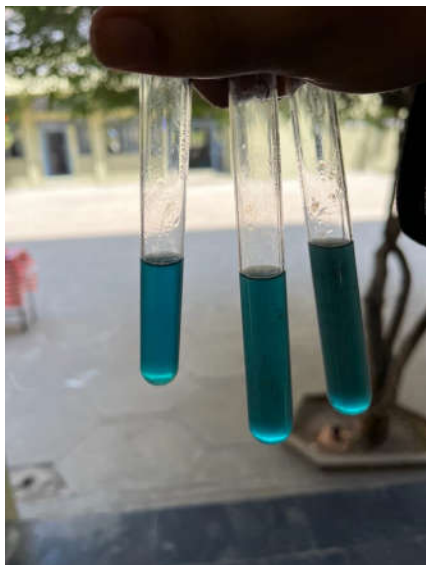
Fig. 3 - Blue colour sample absence of glucose.
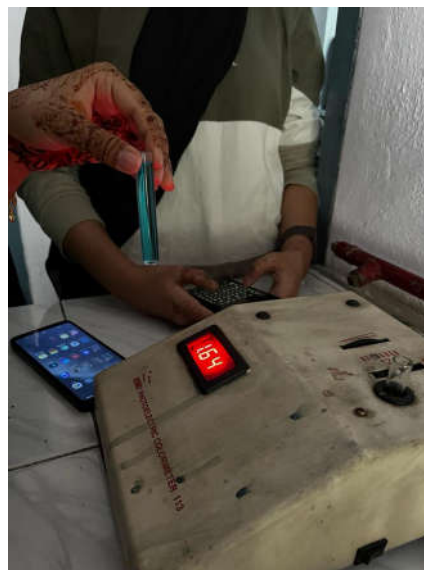
Fig.4 - Determination of O.D values indicating using colorimeter

Interpretation of Benedict's Test

• Blue colour - sugar absent;

• Green colour - 0.5 gm% sugar

• Yellow colour – 1.0 gm% sugar

• Orange colour - 1.5 gm% sugar

• Brick red colour – 2.0 % or more sugar

Results:

The following were the O.D value readings of the colorimeter at wavelength of 540 nm:

Situation 1 -
Fed and adjusted to the environment:

 a) 1.6 for 1.0 ml of sample

 b) 1.0 for 1.5 ml of sample
 c) 1.0 for 2 ml of sample

Situation 2 –
Starved and stressed:

a) 1.07 for 1.0 ml of sample

 b) 1.13 for 1.5 ml of sample

 c) 1.17 for 2.0 ml of sample

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Situation	Volume of sample	O.D Value
1. Fed and adapted	1.0 ml 1.5 ml 2.0 ml	1.6 1.0 1.0
2. Starved and stressed	1.0 ml 1.5 ml 2.0 ml	1.07 1.13 1.17

Table 1.1

As the concentration of glucose increases, the proportion of Benedict's reagent decreases, making the glucose solution less tinted and therefore less viable to the absorption of light, and vice versa.
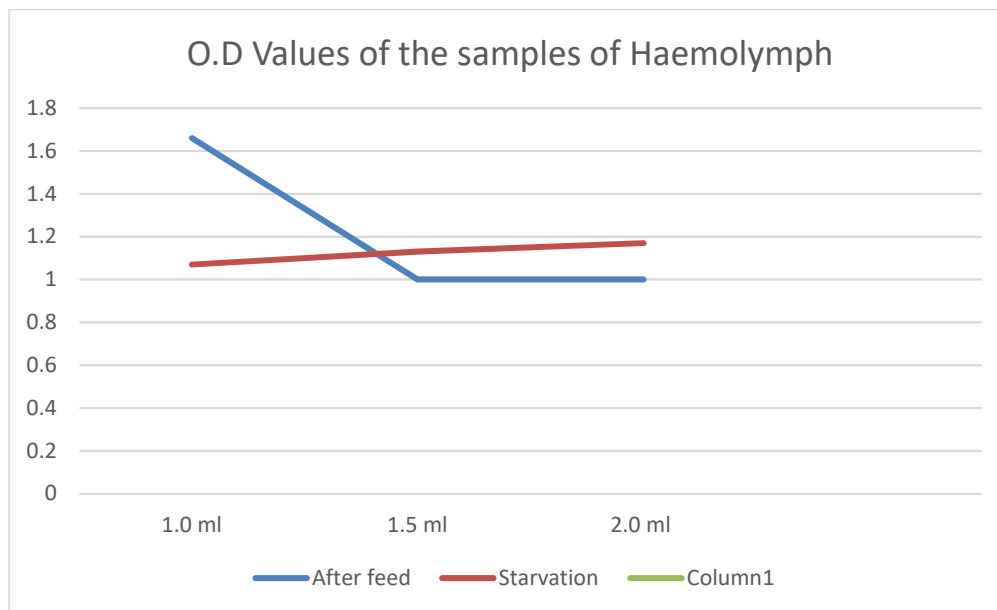
GRAPH 1.1

This graph explains the increase in O.D value due to the decrease of glucose in the haemolymph.

DISCUSSION:

Peptide hormones serve as an intermediate between neurological signalling and terminal hormone signalling (steroid hormones).These peptide hormones are typically released from tissues in response to neurological stimulation, and are transported by the circulatory system to target sites, and bind receptors on the cell surface, Where they stimulate intracellular signal transduction pathways leading to the release of the next hormone in a cascade or directly regulating some physiological action (LeBlanc, 2007).

Glucose regulation is crucial in crustaceans to uphold organ functions and counterbalance various environmental stressors. The breakdown of carbohydrates like starch, glycogen, and disaccharides, along with glucose absorption through the hepatopancreas, primarily contributes to the glucose levels in the haemolymph. The hepatopancreas serves multiple functions. During periods of stress, the metabolic activity of crustaceans escalates, prompting the hepatopancreas to release elevated quantities of glucose into the haemolymph. (Dutra *et al*., 2008).

The most common method for glucose measurement is the colorimetric assay based on the enzymatic oxidation of glucose (Trinder, 1969).Energy metabolism is pivotal for the survival, function, and stress resilience of organisms. The quantity of accessible energy, its acquisition rate, metabolic conversion, and storage capacity are inherently constrained in all organisms.

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Consequently, the control of energy expenditure and its distribution across various functions is crucial for organismal fitness. Environmental stressors can significantly disrupt an organism's energy equilibrium by necessitating extra energy for recuperation and homeostasis maintenance, thereby straining the systems responsible for energy acquisition, conversion, and preservation.(Calow, 1983, 1989; 1991; Calow and Forbes, 1998; Van Straalen and Hoffmann, 2000).

It is observed that *Barytelphusa cunicularis* showed the changes in the haemolymph glucose levels when crabs were exposed to stressful environmental conditions i.e. when the crabs were starved.

CONCLUSION:

The study shows an increase in glucose concentrations during the starved condition, i.e.stressful situation. The release of hormones and the X organ plays an important role in regulation of CHH that may be secreted to stimulate release of glucose stored in the tissues. Hence, the present study shows an increase in haemolymph glucose during starved conditions, which then shows the stored glucose is released for maintaining homeostasis of the body.

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EFFORTS TO ENSURE THE SURVIVAL OF THE GLORIOUS REPTILES

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Abstract:_Birds are important members of many ecosystems.They play a vital role in controlling pests, acting as pollinators, and maintaining island ecology. In addition, birdsare important to humans in many ways, such as serving as a source of food and providing fertilizer in agriculturalsettings. Today, birds are dying in masses, because of environmental factors. Global warming being the foremost is accompanied by other factors like cellular towers, crash with airplanes, etc. The loss of their natural habitats, affects their migration and reproduction patterns. Consequently, this has caused a decline in their number, driving them to extinction. The dwindling green spots in the twin cities have taken a toll on common birds.Thereweretimeswhenhousesparrows(Passerdomestics)wereseen verycommonlyin the cities but off late they have been a rare sight. The people in twin cities would wake up to the melodious voice of koel but it has now become a reality of the past._

The project "Diversity of Birds and their Conservation in twin cities" was taken up with the aim to sensitize citizens about their social responsibility and conserving population of local birds thereby preserving the Biodiversity of birds.

Introduction: The project was undertaken with the aim of providing shelter and food to thebirds inorder to attract them towards he cities back.

Objectives:

- To study the Diversity of Birds in Twin Cities
- To promote Conservation of local species of birds

- To Create awareness among local citizens about the importance of birds and their conservation for human survival.
- To Promote Biodiversity
- To revive the glorious Reptiles in Twin cities

The project was sanctioned in the month of May2022. A total 22,000 Rs were sanctioned for the same by Research Cell of St.Ann's College for Women. Ground work on review of birds in and around Hyderabad was done. Information regarding the habitats of different birds and their nesting habits was collected.

Methodology:

The project was carried out in two phases. The first phase was conservation of birdsbyvarious activities and the second phase involved Awareness on Conservation of Birds.In the first phase,the foremost activity which was performed was the Plantation drive across the twin cities.Plants which are known to be natural habitats of birds were bought and distributed among students, in residential buildings , in GHMC parks, offices havingspace in their premises .

 Theplants distributed were

- ➢ Hibiscus
- ➢ Nandivardhan
- ➢ Pomogranate
- ➢ Badam

➤ Custardapple

➤ Sapota

➤ Daisy

➤ Neem

➤ Harsingar

These plants are known to provide better habitats for birds.

PLANTATION DRIVE

The areas covered were

- KishanBagh
- Mehdipatnam
- Rajendranagar
- Gandhi nagar
- Santoshnagar
- Kalimandi
- Narsingi
- Khairtabad
- Banjarahills,
- Bandlagua
- QutubShahi Tombs
- Begumpet
- Kukatpally
- Nawabsahabkunta
- Tolichowki
- Masabtank
- Chintalmet
- Mallepally
- Langarhouse
- Bhoiguda
- Ghansi Bazar.

Varioust ypes of birds nests were made with natural material like coco coir, bamboo basket, dry grass, tissue paper,twigs,egg shells, leaves and mud based on the types of birds usually seen in the respective areas . The nest were put up to   provide nesting places . At first birds were seen to be Reluctant to enter the nest in most of the areas. In few places positive response was shown by the birds. At few places where the nests were set up, sparrows have laid the eggs which hatched out into chicks and later flew away.

SETTING UP OF BIRDS NESTS IN AREAS FREQUENTED BY THE BIRDS
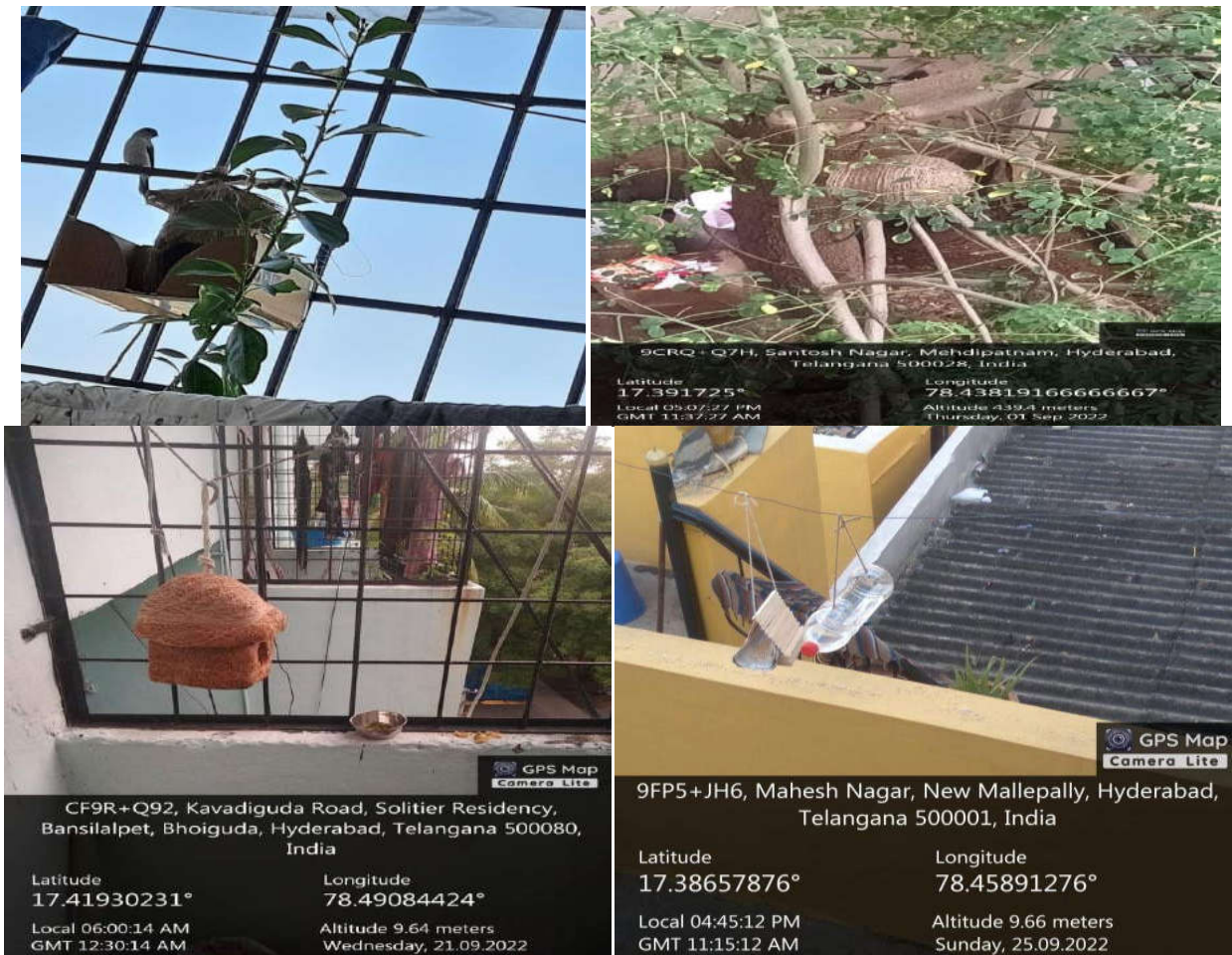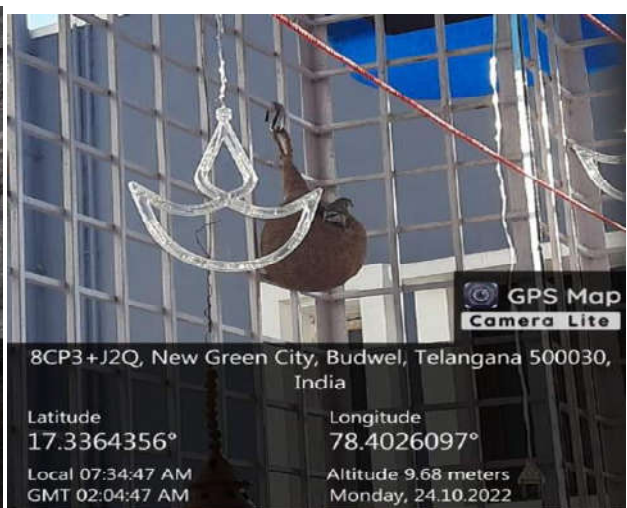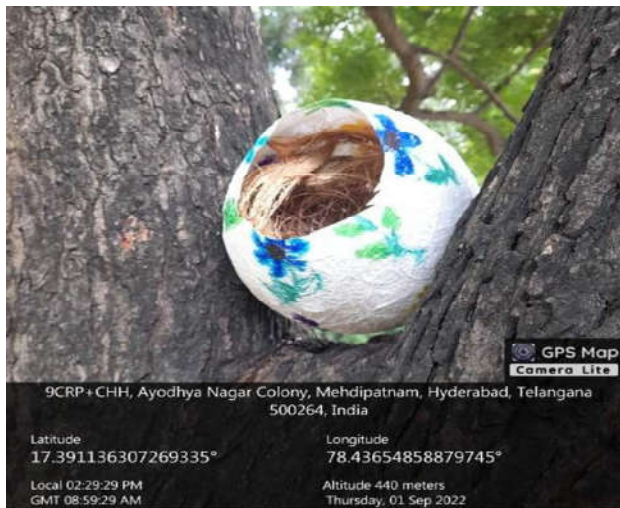
Bird feeders and baths were arranged in different localities. Feeders were made with ice cream sticks, plastic bottle, leaves plastic bottles and paper plates. Few ready made feeders were also used. Huge success was achieved with this action. Birds have frequented places were plants and feeders were kept.

TheBirdsobservedwere

- ➢ Sparrow

- ➢ Koel

- ➢ Myna

- ➢ Parrot

- ➢ Quail

- ➢ Purple sunbird

- ➢ Bulbul

- ➢ Dove.

The following are Geotagged photos for the same.
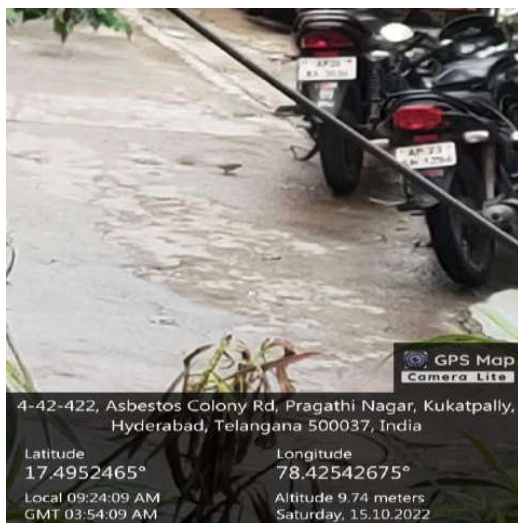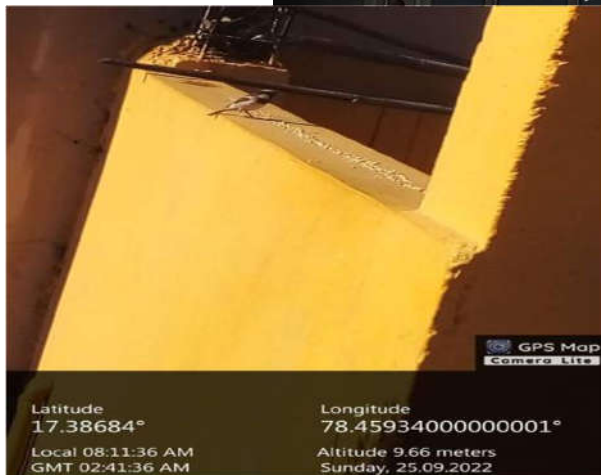
In the second phase of the project, Awareness program on conservation of birds in the form of campaigns , skit and posters was carried out a. Visits to various schools,localities were made for awareness about the importance of conservation of Birds.
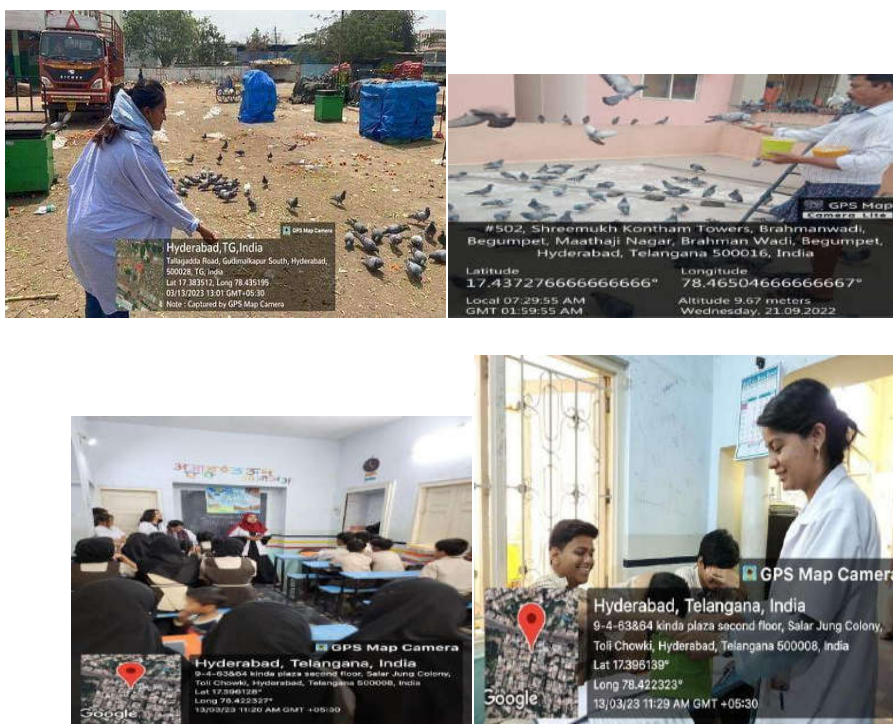
<u>Results:</u>

The overall project was a successful feat.The number of Birds visiting the residential areas due to the plantation drive increased. The bird feeders and baths have been more usefulduting summer season. Awareness campaign has gained marvelous response from general public as well as school students.Birds like Sparrow,Dove and Quail benefited more from

this initiative. The Birds frequently spotted in the twin cities of Hyderabad and Secunderabad were as follows.

Sparrow, Koel, Myna,Parrot, Quail,Purple sunbird,Bulbul Dove.

<u>Discussion and Conclusion:</u>

Though we started the work as a tiny drop in an ocean, we made sure to prove that every drop counts. Our project indicates that a little enthusiasm and hardwork is what is required to bring back our glorious reptiles. There were many hurdles during the project.The birds would not show any response to the plants or nests during the initial stages but as the time passed they started being habituated to the new structures and gradually habituated to it to the extent of laying the eggs too. The awareness campaign was a huge success. This study reflects that modernization and conservation can go hand in hand.

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NATURE'S PEST PATROL- A JOURNEY INTO ORGANIC CONTROL OF COCKROACH

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ABSTRACT: *Cockroaches are common household pests that pose health risks and sanitation concerns. Contemporary methods of cockroach control often involve the use of chemical insecticides, which may raise environmental and health concerns. As a result, there has been growing interest inexploring organic methods for cockroach control that are effective, environmentally friendly, and sustainable.*

This research provides an overview of organic methods for cockroach control, drawing upon a synthesis of scientific literature and field studies. The review begins by discussing the biology and behaviour of cockroaches, highlighting key factors that contribute to their infestation and persistencein indoor environments.

This research highlights the potential of organic methods for cockroach control as viable alternatives to conventional chemical insecticides. By integrating scientific evidence with practical insights, it provides valuable guidance for pest management professionals, policymakers, and homeowners seeking environmentally friendly and sustainable solutions for cockroach infestation. Further research and innovation in organic pest control methods are warranted to address emerging challenges and optimise their efficacy in diverse settings.

KEY WORDS: Contemporary methods,Cockroaches, Chrysanthemum, infestation, pest managemenr

ABBREVIATIONS:

Chrysanthemum Flower Ash:

CFALemon Juice: LJ

Ginger Extract:

GEClove

Powder: CP

INTRODUCTION

In India, popular pest control products include well-known brands, which offer a variety of household insecticides such as aerosol sprays, mosquito coils, and electric vaporizers targeting mosquitoes, flies, and other flying insects. Some widely used brands provide insecticide sprays and mosquito coils effective against common household pests like mosquitoes and cockroaches. These brands specialise in mosquito repellent products, including electric vaporizers, mats, and coils designed to protect against disease-carrying mosquitoes like those responsible for dengue and malaria, some formulated as a gel, specifically targets cockroaches, while some brands offers diverse pest control solutions, including sprays, coils, and mats effective against both flying and crawling insects.

These brands are prevalent choices for households in India, addressing various pest control needs, and it's important for users to adhere to the product instructions for safe and efficient application. The use of pest control chemicals, if not handled with care, can pose potential health risks to humans. Inhaling fumes or aerosols from certain pesticides may lead to respiratory issues, causing coughing or wheezing. Direct contact with these chemicals can result in skin irritation or allergic reactions, particularly for those with sensitive skin, while contact with the eyes may cause redness or more severe problems. Accidental ingestion poses serious health risks, emphasising the importance of safe storage away from food and out of reach of children. Prolonged exposure to pesticides may be associated with chronic health concerns, including neurological and reproductive issues.

Even though there's so many problems being caused to humans, cockroaches have become immune to it. The phenomenon of cockroaches developing resistance to certain pesticides is known as insecticide resistance. Over time, repeated exposure to the same type of pesticide can lead to a natural selection process favouring the survival of cockroaches with genetic traits that make them less susceptible to the pesticide. These resistant individuals then reproduce, passing on their resistance to future generations.

Cockroach Species Found In India:

1) *Blattella germanica* (German cockroach)
- Adult 10-15mm, lifecycle more than 100 days, major pests in restaurants, hotels and apartments mainly in dark and secluded areas like behind the refrigerator or under cupboards.
- Organic methods of killing: peppermint oil, cedarwood oil, Cypress oil, crushed bay leaves and coffee grounds, powdered sugar+boric acid.

Fig. 1 *Blattella germanica*

2) *Periplaneta americana* (American Cockroach)
- Adult 35-40mm, largest pest cockroach, shining red chocolate brown in colour, life cycle 100 days to 3 years. Prefers a warm and humid environment such as drains and sewers, borewells.
- Organic methods of killing: Boric acid, hot water, baking soda+LJ, crushed Garlic cloves.

Fig. 2 *Periplaneta americana*

3) *Supella longipalpa* (Brown banded cockroach)
- Adult 10-14mm, smallest pest cockroach, yellow brown stripes across abdomen, life cycle 90 to 115 days, warm and humid environments
- Organic methods of killing: Baking soda+sugar, boric acid, Vinegar, petroleum jelly.

Fig. 3 *Supella longipalpa*

4) *Blatta orientalis* (Oriental cockroach)

- Adult 25-32 mm, dark brown species, live up to 170 days. They rather run than fly and can tolerate lower temps than other cockroaches
- Organic methods of killing: baking soda+water because they need water to live. These are some methods used to get rid of cockroaches in old days

Fig. 4 *Blatta orientalis*

Factors contributing to insecticide resistance in cockroaches include:

1. Overreliance on a Single Chemical: Continuous use of a specific type of pesticide can accelerate the development of resistance within cockroach populations.
2. Incomplete Elimination: If a pesticide application fails to eliminate the entire cockroach population, surviving individuals may carry resistance genes, contributing to a more resilient population.
3. Adaptability: Cockroaches have shown a remarkable ability to adapt to changing environments, including exposure to pesticides, through genetic variations that confer resistance.

Around 4000 different species but only about 40 are considered pests among which only 4 are found in the Southern part of India.
Repellant sprays often used to treat symptoms i.e. temporarily stop them from entering but not the cure, to eliminate their breeding ground.

Location of cockroach infestation:
Bathrooms, kitchens, laundry rooms, basements, drains

Contemporary ways of killing cockroaches:

The traditional ways use borax or bleach as it can be very effective. Using Phosphorus paste as bait was effective against american cockroaches and then they were stomped and they would smoke up. In the mediaeval era, people used crushed and dried chrysanthemum flower petals to make insecticidal dust, and simple ash can also be used. It causes drying out of the pheromone pads on their feet and may cause death. Garlic oil and black pepper were also used.

MATERIALS USED

This project focuses on the development of organic formulations for cockroach control, utilising a combination of natural ingredients, including Chrysanthemum flower extract, phosphorus, Vinegar, LJ, GE, Atta (wheat flour) and Maida (all-purpose flour). The aim is to explore the synergistic effects of these ingredients in targeting and controlling cockroach populations while minimising environmental impact and ensuring safety for human health.

Each ingredient was carefully selected based on its known pesticidal properties, availability, and compatibility with other components of the formulation. CFA and phosphorus serve as the primary active ingredients, providing natural insecticidal action against cockroaches. Vinegar and LJ contribute acidity, acting as deterrents and disinfectants, while GE adds additional repellent properties.

The inclusion of Atta (wheat flour) and Maida (all-purpose flour) serves as carriers for the active ingredients, enhancing adhesion and dispersion of the formulation. Moreover, these ingredients offer supplementary benefits such as attracting cockroaches and facilitating ingestion of the active compounds.

The project methodology involved systematic experimentation to optimise the formulation composition and concentration of each ingredient. Various formulations were tested for efficacy, safety, and practicality, with emphasis on minimising environmental impact and ensuring ease of application in domestic settings.

By harnessing the combined effects of CFA, phosphorus, Vinegar, LJ, GE, Atta (wheat flour) and Maida (all-purpose flour), the project aims to offer a sustainable and environmentally friendly alternative to conventional chemical insecticides.

1. Chrysanthemum flower:

Chrysanthemum flower is an organic method for cockroach control. Two batches of Chrysanthemum flowers were prepared using different drying methods, namely sun drying and oven drying, followed by crushing into ashes. The effectiveness of these preparations was evaluated in controlling cockroach infestations.

Preparation of CFA:
Two batches of Chrysanthemum flowers were harvested and dried using two different methods: sun drying and oven drying. The sun-dried batch was exposed to direct sunlight for one to two days until fully dried. The oven-dried batch was dried at a controlled temperature of 800° Celsius for 30 minutes.

Once dried, both batches were manually crushed into ash. The ash obtained from both batches of Chrysanthemum flowers served as the primary ingredient in the organic cockroach control formulation.

The utilisation of CFA represents a natural and environmentally friendly approach to pest control, with potential implications for sustainable pest management practices.

Fig. 5 Chrysanthemum flower

Fig. 6 Chrysanthemum flower ash

2. Phosphorus powder:

Phosphorus was used as a supplementary ingredient, in conjunction with CFA. Phosphorus, obtained in a significantly smaller quantity relative to the CFA (800 grams), was selected for its availability and potential synergistic effects in pest control applications.

A judicious amount of phosphorus was incorporated into the organic formulation, keeping in consideration its potency and compatibility with the CFA. The ash quantity utilised was meticulously determined through preliminary experimentation and optimization to ensure optimal efficacy without compromising safety or environmental sustainability.

3. <u>Vinegar:</u>

Vinegar is a natural ingredient in organic cockroach control formulations. Vinegar, known for its acidic properties and antimicrobial effects, is evaluated for its ability to repel, deter, and eliminate cockroach infestations while maintaining environmental sustainability and human safety.

Each batch of the palettes consisted of 5 ml of Vinegar, with a total of six batches prepared for experimentation. The efficacy of Vinegar in controlling cockroach populations was assessed as part of this project. Each formulation is meticulously designed and tested to optimise Vinegar concentration, compatibility with other ingredients, and effectiveness against cockroach populations.

4. <u>Lemon Juice:</u>

LJ is a supplementary ingredient in organic cockroach control formulations. With a minimal dosage of 1 ml, LJ's acidic properties are hypothesised to enhance the repellent and insecticidal effects of the formulation when combined with other natural ingredients such as, GE, Atta (wheat flour).

The methodology involves the systematic integration of LJ into experimental cockroach control formulations, followed by comprehensive testing to assess its impact on formulation efficacy.

5. <u>Ginger Extract:</u>

GE is utilised in a minimal dosage of 1 ml, as a novel ingredient in organic cockroach control formulations. GE, renowned for its bioactive compounds and repellent properties, is hypothesised to contribute to the formulation's insecticidal effectiveness when combined with other natural ingredients, like LJ, atta.

Methodology involves the systematic incorporation of GE into select cockroach control formulations, followed by rigorous testing to evaluate its impact on formulation performance. Each formulation is meticulously prepared and evaluated for its ability to repel, deter, and eradicate cockroach populations under controlled laboratory conditions.

Experimental trials are conducted to assess cockroach response to GE-based formulations, employing standardised protocols and statistical analyses to quantify repellency and mortality rates. Comparative studies are also conducted to elucidate potential synergistic interactions between GE and other active ingredients, aiming to optimise formulation efficacy.

6. Atta (Wheat flour)

Atta (wheat flour) is a key component in organic cockroach control formulations. Utilising a total quantity of 500 grams across two experiments, atta's adhesive and baiting properties are evaluated for their potential to enhance the effectiveness of formulations in attracting and eliminating cockroach populations.

The experimental design encompasses two distinct approaches to incorporating Atta into cockroach control formulations. In the first experiment, Atta serves as a carrier for active ingredients such as LJ, and GE. The formulation is prepared to optimise adhesion and dispersion, aiming to increase cockroach exposure and ingestion of the active compounds.

In the second experiment, Atta is utilised as a baiting agent in combination with CFA, phosphorus and Vinegar. The formulation is strategically deployed in areas of high cockroach activity, exploiting atta's attractiveness to cockroaches to lure them into contact with the insecticidal components.

Cockroach response to the formulations is monitored and evaluated through systematic observation and focusing on factors such as attraction and mortality rates.

7. Laung (Clove Powder)

CP is a natural insecticidal agent in organic cockroach control formulation. With a quantity of 100 grams allocated for a single experiment, CP's potential as an active ingredient in pest management is explored, aiming to provide an environmentally friendly and sustainable alternative to conventional chemical insecticides.

The experimental methodology involves the integration of CP into a formulation alongside other natural ingredients, such as Vinegar, and all-purpose flour. The formulation is carefully prepared to optimise the dispersion and concentration of CP, ensuring maximum efficacy against cockroach infestations.

8. Maida (All purpose flour)

Maida (all-purpose flour) is a versatile ingredient in organic cockroach control formulations across three distinct experiments. With a total quantity of 700 grams allocated, Maida's adhesive properties and potential as a carrier for active ingredients are investigated to optimise formulation efficacy in repelling and eliminating cockroach infestations.

In the first experiment, Maida serves as a primary component in a formulation combined with CFA, phosphorus and Vinegar. The formulation is prepared to ensure even dispersion and optimal adhesion to surfaces frequented by cockroaches, facilitating exposure and ingestion of the active compounds.

In the second experiment, Maida is integrated into a baiting formulation alongside CP and Vinegar. Deployed strategically in areas of high cockroach activity, the formulation capitalises on Maida's attractiveness to lure cockroaches into contact with the insecticidal components, resulting in enhanced efficacy in pest control.

The third experiment explores Maida's potential as a standalone agent for cockroach control. Utilising Maida in combination with CFA, Phosphorus and Vinegar, the formulation is evaluated for its ability to deter cockroach infestations and disrupt their reproductive cycles, offering a sustainable alternative to conventional chemical insecticides.

Each experiment is conducted under controlled laboratory conditions, with standardised protocols for formulation preparation, application, and monitoring of cockroach response. Data analysis includes quantitative assessment of cockroach mortality rates, repellency, and residual efficacy to determine the effectiveness of Maida-based formulations.

The findings of this study contribute to the understanding of LJ's role in organic pest management and its potential applications in sustainable cockroach control strategies. By harnessing the natural properties of LJ and integrating it into organic cockroach control formulations, this research aims to offer environmentally friendly alternatives to conventional chemical insecticides.

METHODOLOGY

FORMULATION 1

MATERIALS

LJ, GE, Atta (flour), Gloves, Mask.

PREPARATION OF PELLETS
- Ingredients:
  - LJ, GE, atta(flour)
- Mixing procedure:
  - We took Atta in the petri dish. We added LJ and GE and mixed it and made a dough then divided it into small balls/palettes.

Fig. 7

FORMULATION 2

MATERIALS

Chrysanthemum, Phosphorus, Vinegar, Atta (flour), Gloves, Mask.

PREPARATION OF PELLET
- Ingredients:
    - CFA, Phosphorus, Vinegar, Atta(flour)
- Mixing procedure:
    - We mixed the dry ingredients first i,e., Atta CFA and Phosphorus powder, then we added Vinegar, and mixed it and made a dough and divided it into small balls/palettes.

Fig. 8

FORMULATION 3

MATERIALS

Chrysanthemum, Phosphorus, Vinegar, Maida (All purpose flour), Gloves, Mask.

PREPARATION OF PELLETS
- Ingredients:
  - CFA, Phosphorus, Vinegar, Maida(all purpose flour)
- Mixing procedure:
  - We mixed the dry ingredients first i,e., CFA and Phosphorus powder, Maida then we added Vinegar, and mixed them and made a dough and divided it into small balls/palettes.

Fig. 9

FORMULATION 4

MATERIALS
    CP, Maida (All purpose flour), Vinegar, Gloves, Mask.

PREPARATION OF PELLETS
- Ingredients:
    - CP, Maida (All purpose flour), Vinegar.
- Mixing procedure:
    - We mixed the dry ingredients first i.e., Maida and CP, then we added Vinegar and mixed it and made a dough and divided it into small balls/ pellets .

Fig. 10

FORMULATION 5

MATERIALS
  CFA, Vinegar, Gloves, Mask.

PREPARATION OF pellets
- Ingredients:
  - CFA and Vinegar.
- Mixing procedure:
  - Vinegar was added to the CFA and was mixed well and made into small balls/ pellets

Fig. 11

FORMULATION 6

MATERIALS

  CFA, Maida (All purpose flour) and Vinegar, Gloves, Mask.

PREPARATION OF pellets
- Ingredients:
  - CFA, Maida (All purpose flour) and Vinegar.
- Mixing procedure:
  - We mixed the dry ingredients first i.e., Maida, and CFA then we added Vinegar and made a dough then divided it into small balls/pellets .
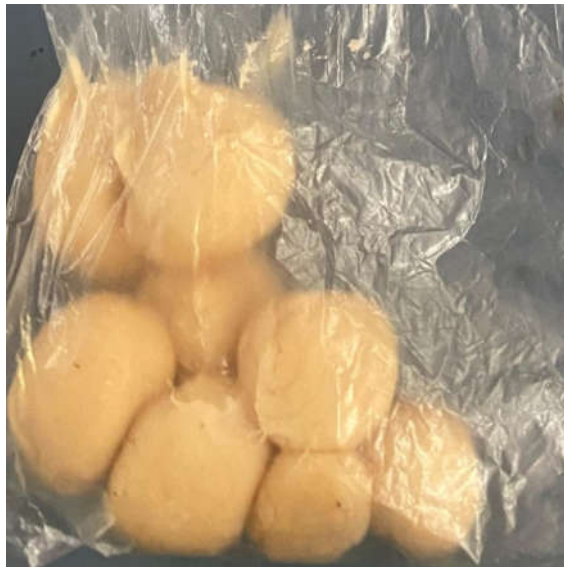
Fig. 12

EXPERIMENTAL DESIGN

Location:
The experiment was conducted in a residential setting, specifically targeting a house with a notable cockroach infestation. The choice of location was based on the observed high cockroach activity within the premises.

Population:
Rather than predefining a specific number of cockroaches, the experiment aimed to address the existing population within the selected residence. The approach involved strategically placing the pellets in areas where heightened cockroach presence had been observed.

Application of pellets:
The poison was administered in accordance with the identified areas of increased cockroach activity within the house. Dosage was determined based on the extent of the observed infestation, ensuring an appropriate and proportional application.

OBSERVATION

Days	LJ, GE, Atta	CFA, Vinegar	CFA, Maida, Vinegar	CP, Vinegar, Maida	Vinegar, CFA, Atta, Phosphorous	CFA, Maida, Phosphorous, Vinegar
1	0	0	0	0	0	0
2	0	3	1	0	0	0
3	5	4	1	0	1	2
4	4	4	0	1	0	1
5	6	5	1	1	0	2
6	6	7	0	2	1	1
7	5	8	0	0	2	0
8	8	8	2	0	0	0
9	7	7	0	0	0	0
10	9	9	0	0	0	1
11	0	2	-	-	-	-
12	2	3	-	-	-	-
13	2	1	-	-	-	-
14	4	4	-	-	-	-
15	3	6	-	-	-	-

Table 1 - Observation

FORMULATIONS WITH DESIRED RESULT

Graph 1
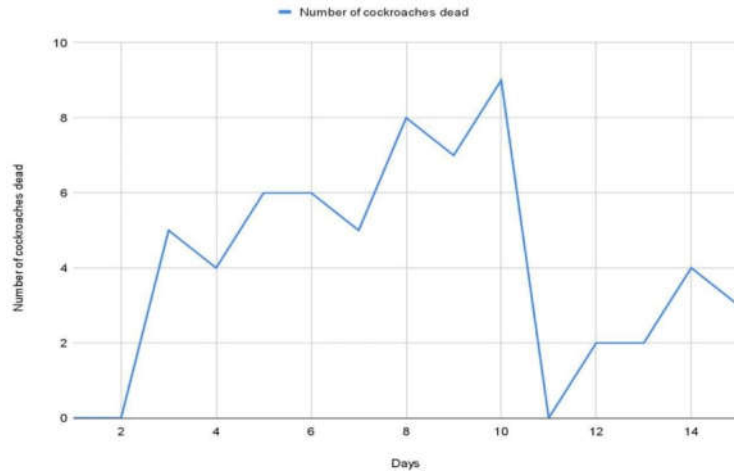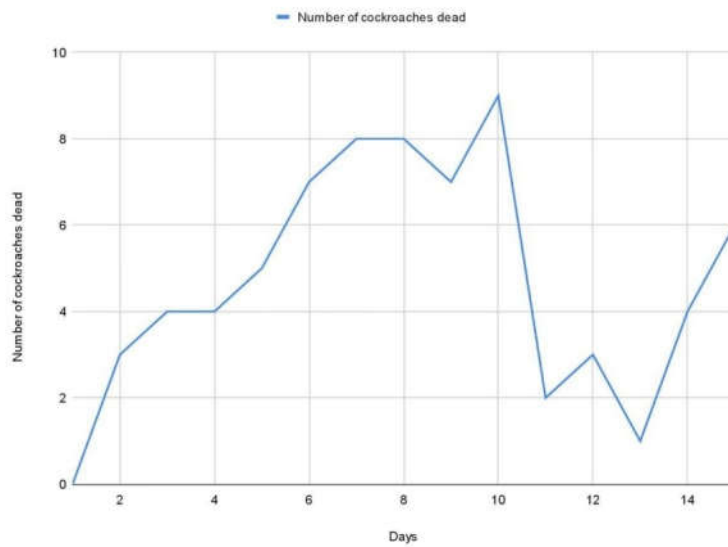
Graph 2

OTHER FOUR FORMULATIONS
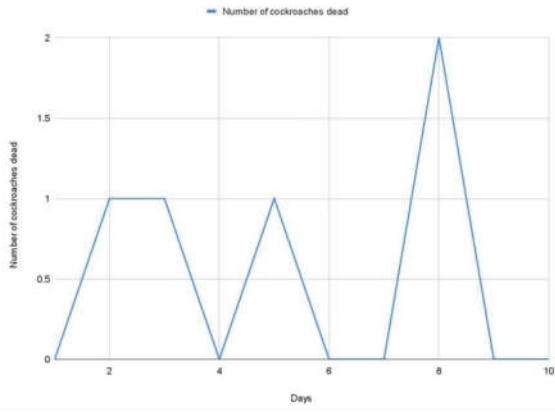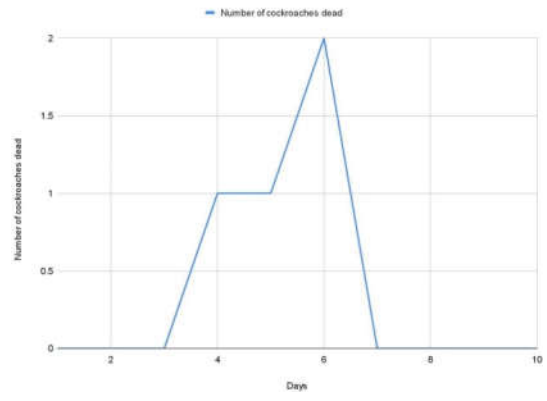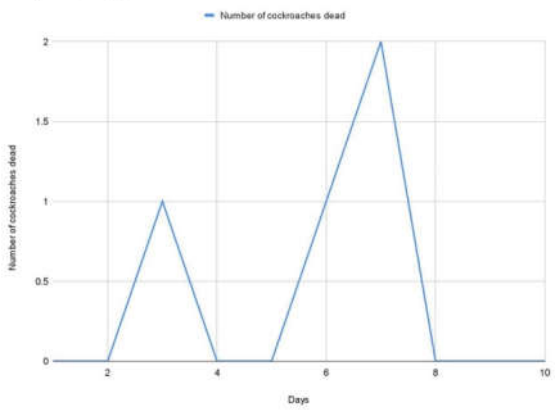
Graph 3
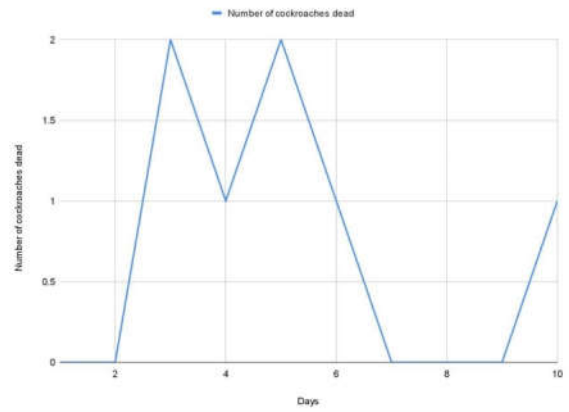
Graph 4

Graph 5

Graph 6

a. CFA and Vinegar

b. CFA and Vinegar

c. LJ, GE, Atta (wheat flour)

d. LJ, GE, Atta (wheat flour)

e. CFA, Maida and Vinegar

f. CP, Maida, Vinegar

(a-f Cockroaches affected by the pellets)

RESULT

The aim of our project was to explore contemporary methods of cockroach control at the household level. Through rigorous experimentation, we evaluated the efficacy of six formulations in mitigating cockroach infestations, aiming to identify effective and environmentally friendly solutions for pest management.

Despite the pellets only being moderately useful, they did serve as attractive substrates for egg-laying. Cockroaches were observed laying eggs on the surfaces of the pellets, indicating that the pellets provided a conducive environment for reproduction. However, upon closer examination, it was noted that the laid eggs did not rupture or produce offspring as expected.

This observation suggests that while the pellets may have provided a suitable surface for egg-laying, they possessed properties that interfered with the normal development of cockroach eggs or larvae. This limited impact on cockroach reproduction indicates a partial efficacy of the pellet formulations, as they disrupted the reproductive cycle of the insects to some extent.

Upon comprehensive analysis of the experimental data, it was observed that two out of the six formulations yielded exceptional results, surpassing initial expectations. The LJ, GE, and Atta formulation, along with the CFA and Vinegar formulation, demonstrated remarkable effectiveness in controlling cockroach populations. These formulations exhibited significant cockroach mortality rates and effectively deterred further infestations, showcasing their potential as viable options for organic cockroach control.

Throughout the experimentation process, a total of 152 cockroaches were recorded as either deceased or affected by the formulations in a time period of 70 days. While this represents a significant impact on cockroach populations, it also underscores the persistent challenge of effectively managing pest infestations in domestic settings. The results of our project highlight the importance of continued research and innovation in developing sustainable and efficacious methods of cockroach control, emphasising the need for holistic approaches that prioritise both effectiveness and environmental sustainability.

FORMULATIONS WITH DESIRED RESULTS

GE, LJ and Atta (Wheat Flour):

Contrary to expectations, the GE and flour pellets with LJ addition did not demonstrate significant repellent effects on cockroaches. While the pellets emitted a pungent smell characteristic of Ginger and Lemon, there was no observable reduction in cockroach activity compared to the control group. Cockroaches appeared indifferent to the presence of the pellets, exhibiting similar behaviour and activity levels as in areas with no treatment.

CFA and Vinegar:

The pellets made from CFA and Vinegar demonstrated high effectiveness in repelling cockroaches initially. Cockroaches exhibited aversion to the pellets, likely due to the combined effects of the insecticidal properties of CFA and the acidic odour of Vinegar. However, over time, the effectiveness of the pellets diminished as the odour of Vinegar dissipated.

Observations revealed that the repellent effect lasted for a certain period, typically a few days to a week, depending on environmental conditions such as humidity and ventilation. Once the Vinegar lost its characteristic smell, the pellets became ineffective, and cockroach activity resumed in the treated areas. Subsequent observations indicated that cockroaches showed no aversion to the pellets once the Vinegar odour dissipated, suggesting that the repellent effect was primarily odour-dependent.

The effectiveness of the CFA and Vinegar pellets as a short-term cockroach repellent can be attributed to the combined action of pyrethrins in the CFA and the acidic odour of Vinegar. Pyrethrins are known to have insecticidal properties and can repel insects upon contact or inhalation. Additionally, the acidic odour of Vinegar may act as a deterrent for cockroaches, disrupting their olfactory receptors and navigation cues.

However, the short duration of effectiveness observed in this experiment highlights a limitation of using Vinegar as a repellent component. Vinegar is volatile and prone to rapid evaporation, leading to the loss of its odour over time. As a result, the repellent effect of the pellets is transient and requires frequent replenishment to maintain efficacy, which may not be practical for long-term cockroach control strategies.

OTHER FOUR FORMULATIONS

1. CFA, Phosphorus, Vinegar, Atta
2. CFA, Phosphorus, Vinegar, Maida
3. Cloves, Maida, Vinegar
4. CFA, Maida, Vinegar

Although the four formulations showcased unique combinations of natural ingredients, their effectiveness in controlling cockroach populations provided valuable insights and opportunities for learning. Each formulation contributed to our exploration of sustainable and environmentally friendly approaches to pest control, highlighting the diversity and potential of organic methods in tackling infestations. Our experimentation with these formulations sparked creativity and innovation within our team, encouraging us to think outside the box and explore unconventional solutions to the challenge of cockroach management.

Furthermore, the process of refining and optimising these formulations prompted us to critically evaluate our methodologies and experiment with adjustments. By identifying areas for enhancement, we iteratively improved our experimental techniques and sought to optimise the performance of subsequent formulations. This iterative process of learning and adaptation underscored the importance of resilience and perseverance in scientific inquiry, ultimately contributing to our growth and development as researchers and problem-solvers.

DISCUSSION

The observed partial efficacy of the pellet formulations may be attributed to several factors. It is possible that the ingredients used in the formulations possessed properties that inhibited egg development or larvae survival, thereby limiting the reproductive success of the cockroaches. Additionally, the physical structure of the pellets may have hindered egg viability or provided an inhospitable environment for larvae development.

Furthermore, the presence of ingredients such as chrysanthemum ash, phosphorus, vinegar, all-purpose flour, and cloves may have deterred cockroaches from actively colonizing the treated areas, contributing to a reduction in overall cockroach population despite the limited impact on reproduction.

CONCLUSION

Our project on cockroach control has been an eye-opening experience. While we had high hopes for all six formulations, it became clear that only two really did the trick. The Lemon Juice, Ginger Extract, and Atta mix, along with the Chrysanthemum Flower Ash and Vinegar combination, proved to be real winners, significantly reducing cockroach numbers in our tests.

On the flip side, the other four formulations didn't quite live up to our expectations. Despite our best efforts, they just didn't seem to have the same impact on the cockroach population. It's disappointing, but it's also a valuable lesson. Sometimes, even with the best intentions, things don't always go as planned.

Throughout the project, we saw a total of 152 cockroaches getting affected by the formulations in a time period of 70 days. While this number is significant, it also shows that we still have a lot of work to do in finding the most effective and sustainable ways to control pests in our homes.

In the end, this project taught us the importance of perseverance and adaptability. We may not have found the perfect solution yet, but we've gained valuable insights that will guide us in future experiments. By continuing to explore new ideas and techniques, we believe we can eventually find a method that works wonders for cockroach control while keeping our homes safe and eco-friendly.

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FROM OCEANS TO ORGANISMS: THE IMPACT OF MICROPLASTICS

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Abstract:

Plastic is a synthetic material made from a wide range of organic polymers that can be molded into shape while soft and then set into a rigid or slightly elastic form. Plastics are used in a multitude f applications due to their versatility, durability, and cost-effectiveness

Plastic, ubiquitously, found its way into the household like a virus. Leeching people of their health. As true as it is the most available, durable and cost effective it may seem but it is a source of harmful components. In recent years, the microplastics have become a menace to humans. Microplastics have seeped into our ecosystem so deep that it is next to impossible to imagine human life without its sources. Due to its omnipresence in human society, the adverse effects of microplastics are no longer an issue to ignore. The present paper reviews the sources, effects and few remedial measures to overcome the disastrous epidemic.

Introduction:

Microplastics, defined as tiny plastic particles measuring less than 5mm, originate from various sources. They primarily result from the degradation of larger plastic debris and are found not only in oceans and seas but also in landfills, thereby disrupting natural ecosystems. Marine organisms, ranging from plankton to whales, as well as substances like drinking water, honey, and salt, have been found to contain microplastics.Microplastics are categorized into primary and secondary types. Primary microplastics are intentionally manufactured for specific

uses such as cosmetics and sports surfaces, while secondary microplastics form through the fragmentation of larger plastic items in the environment. Estimating the quantity of microplastics released into the environment is challenging due to numerous sources and the lack of standardized measurement methods.

Research indicates that approximately 14 million tonnes of microplastics have accumulated on the ocean floor globally, with an additional 1.5 million tonnes entering the oceans annually. The sources of microplastics include spills during production, wear and tear of plastic products like car tires, and the degradation of paints, coatings, and synthetic textiles.Moreover, microplastics have been detected in various environmental compartments such as air, water, soil, and even in rain and snow. Their pervasive presence is linked to widespread plastic use in food packaging, which can lead to interactions between packaging materials and food contents, potentially compromising food safety and quality.

A study by the Indian Institute of Technology (IIT) Kharagpur has revealed that disposable paper cups are not safe for drinking tea. The study also found out that if a person consumes three cups of tea in them in a day in that case he/she will end up ingesting 75,000 tiny microplastic particles.

Animal studies have shown that once ingested, microplastics can distribute throughout the body, affecting organs including the liver, spleen, heart, lungs, reproductive organs, kidneys, and brain. This contamination poses risks to both environmental and human health, underscoring the urgent need for effective mitigation strategies.

Sources of Microplastics

The following are some of the most important and frequent sources of Microplastics, the path of entry in human body including the harmful effects

Sources of Microplastics	Path of entry in human body	Lethal effects
Food processing equipment	They may have plastic parts or coatings, tiny plastic residues might mix with the food products	☐ Human Health Effects: Health Risks: While the full extent of health risks is still being studied, there are concerns that microplastics and associated chemicals could contribute to inflammation, oxidative stress, and other health problems.
Food storage items, **infant milk bottles, water bottles**	The food stored in plastic containers; vegetables and fruits that are stored in polythene covers in the refrigerator may contain microplastic.	
Beverages	Heavy metal leaching from plastic additives is strongly pH-dependent.	Endocrine disruptors like BPA and Phthalates can throw off the delicate balance of hormones in our bodies, affecting processes like growth, metabolism, and reproductive health.
Air and environment	Airborne microplastics settling on crops in fields or during transport, finding their way into our food.	
Agricultural practices	**Plastic sheets used to cover the soil or where irrigation systems carry microplastics. These particles could end**	PVC is also called as poison plastic. When heated highly toxic compounds like hydrogen chloride which is a corrosive, highly toxic gas that

Water resources	up on the fruits and veggies we eat. **Sea animals are unknowingly consuming minuscule plastic particles. When people enjoy seafood, they might inadvertently consume these tiny bits too, as they're present in seafood**	can burn skin and cause severe, permanent respiratory damage. ☐ Environmental Impact: • They disrupt ecosystems by entering food chains and affecting organisms at different levels. • Habitat Alteration: Microplastics can alter habitats, such as coastal areas and riverbeds, affecting the organisms that rely on these habitats for survival.
Sanitary Napkins	**Sanitary napkins can contain microplastics as a result of the materials used in their production. These microplastics can come from synthetic fibers such as polyester, polyethylene, polypropylene, and others commonly used in the absorbent core and outer layers of the napkin.**	• Chemical Contamination: Microplastics can absorb and concentrate toxic chemicals from the surrounding environment. These chemicals can then be released into organisms when **ingested, causing harmful effects.** ☐ **Impact on Marine Life:**
Plastic cutting boards	**The repetitive action of cutting and chopping on plastic Boards can cause tiny fragments of the material to break off, releasing microplastics into the food. Washing plastic chopping boards, especially with abrasive sponges or brushes, can wear down the surface and contribute to the**	• **Ingestion: Marine organisms, including fish, seabirds, and marine mammals, often mistake microplastics for food. This**

Beauty Products	shedding of microplastic particles	ingestion can lead to blockages in digestive tracts, reduced feeding efficiency, and malnutrition.
	BisphenolA(BPA):beauty product containers, potentially adding a twist to our skincare routine by messing with our hormonal balance.	• Toxicity: Microplastics can release additives and absorbed pollutants inside marine organisms, potentially leading to toxicity and negative health effects.
	Polyethylene(PE)and Polypropylene(PP):these plastic material holding your favorite cream or serum. While	☐ Pollution and Persistence:
	they're handy for packaging, there's a chance they might sneak into our products overtime or with a bit ofheat. Polystyrene(PS):the material is used in some brushes or tools we use. While it helps shape our beauty routine, it's essential to be cautious about potential exposure.	• Persistent Pollution: Microplastics are highly persistent in the environment, taking hundreds of years to degrade. This persistence means they continue to accumulate in ecosystems over time.
	Vinyl Chloride: An ingredient in some nail products,adding a dash of concern due to its potential long-term effects on our health.	• Transport of Harmful Organisms: Microplastics can act as vectors, transporting harmful organisms and pathogens across ecosystems

Alternatives to plastic use and Avoiding Microplastics:

There are several alternatives to traditional plastics that are being increasingly explored and adopted to mitigate environmental impacts. Here are some key alternatives:

1. **Bioplastics**: These are plastics derived from renewable biomass sources such as corn starch, sugarcane, potato starch, or cellulose. Bioplastics can be either biodegradable (break down into natural components under specific conditions) or non-biodegradable (still derived from renewable sources but do not necessarily degrade completely).

2. **Bio-based Plastics**: Similar to bioplastics, bio-based plastics are made from renewable biomass sources but may not always be biodegradable. They can offer a reduced carbon footprint compared to traditional plastics made from fossil fuels.

3. **Compostable Plastics**: These are plastics designed to break down into carbon dioxide, water, and biomass in composting facilities under specific conditions. They are often used for products like food packaging and bags.

4. **Paper and Cardboard**: These materials are widely used as alternatives to plastic for packaging, disposable cups, plates, and utensils. They are renewable, recyclable, and generally biodegradable.

5. **Glass**: Glass containers and products offer a durable and reusable alternative to plastic. While heavier and more fragile, glass is recyclable and does not leach chemicals into food or beverages.

6. **Metal**: Metals such as aluminum and stainless steel are used for packaging (e.g., cans) and reusable products like water bottles and food containers. They are durable, recyclable, and have a long lifespan.

7. **Natural Fibers**: Materials like cotton, hemp, jute, and bamboo are being used to produce textiles, bags, and even some packaging materials. These fibers are renewable and biodegradable.

8. **Mycelium**: Mushroom-based materials are being researched for packaging and construction. Mycelium-based products are biodegradable, lightweight, and can be molded into various shapes.

9. **Recycled Plastics**: Using recycled plastics reduces the demand for virgin plastics and helps mitigate environmental impacts associated with plastic production and disposal.

10. **Edible Packaging**: Some innovative solutions involve using edible materials (e.g., seaweed-based films) as packaging.

These alternatives vary in their properties, costs, and suitability for different applications. Increasing consumer awareness, technological advancements, and regulatory support are driving the adoption of these alternatives to reduce plastic pollution and promote sustainable practices.

Conclusion

Long-term use of plastic and plastic-derived products poses significant toxicity risks, impacting both human and animal health. Despite its widespread adoption for reasons like durability, availability, and cost-effectiveness, the hazards associated with plastic often go unnoticed by consumers. This unawareness comes at a steep price: plastic gradually poisons living beings and becomes a source of various diseases over time.

While ongoing research continues to explore these impacts, studies have already provided substantial evidence highlighting the dangers of plastic use. The introduction of plastic into the world has brought about profound environmental changes, exacerbating climate issues and becoming a major source of pollution across air, water, and land. This pollution significantly contributes to the degradation of our environment.

The accumulation of plastic waste in the environment is exacerbated by the inefficiencies in waste management systems, particularly in the collection and disposal of end-of-life plastic products. This accumulation contributes significantly to the pollution of terrestrial and aquatic environments worldwide.

Addressing these challenges requires concerted efforts across various sectors, including improvements in packaging materials, enhanced waste management practices, and policies aimed at reducing plastic consumption and promoting recycling. Public awareness and advocacy are also crucial in fostering sustainable practices and mitigating the harmful impacts of plastic pollution on ecosystems and human health.

Efforts to reduce plastic waste would require a multi-pronged approach involving government policies, community engagement, technological innovation, and behavioral change among residents and businesses. Collaboration between stakeholders is crucial to achieving sustainable waste management practices and reducing the environmental impact of plastic waste.

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From Contamination To Conservation: Analyzing Durgam Cheruvu Pollution Challenges

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Abstract

Durgam Cheruvu, also known as Raidurgam Cheruvu, is an 83-acre freshwater lake near Hyderabad, Telangana, India. Historically significant and once a secluded natural haven, it has recently transformed into a popular tourist destination, partly due to the inauguration of the Durgam Cheruvu Cable Bridge in 2020. However, this evolution has been accompanied by severe environmental challenges, notably significant water pollution from untreated sewage and industrial waste, which have drastically impacted the lake's ecosystem and water quality. This study aims to provide a comprehensive analysis of Durgam Cheruvu's historical importance, current pollution levels, and ongoing conservation efforts.

Utilizing data from a variety of credible sources, including academic journals, scholarly books, and reputable news outlets, the research delves into the lake's transformation over the years. The analysis reveals that the lake has been a crucial water source since the Qutb Shahi dynasty (1534-1724), but unchecked urbanization and inadequate waste management have led to its current degraded state. Historical records and recent studies underscore the severity of the pollution, highlighting contaminants such as pharmaceuticals, herbicides, and even cocaine.

The study outlines the efforts made over the years to mitigate these issues, including the construction of sewage treatment plants and bio-remediation initiatives. Despite these measures, illegal constructions and improper waste disposal continue to pose significant threats to the lake's health.

The discussion emphasizes the urgent need for a multi-faceted strategy to address these challenges. Recommendations include stringent regulations on waste disposal, upgrading wastewater treatment infrastructure, and increasing public awareness. The revival of Durgam Cheruvu requires collaborative efforts from local communities, government agencies, environmental organizations, and research institutions. The future of the lake is not only an environmental concern but also a matter of public health and ecological well-being. This study highlights the critical need for swift and decisive action to restore Durgam Cheruvu to its former glory.

KEYWORDS: □ Durgam Cheruvu

□

Water pollution,Untreated sewage,Industrial waste,Urbanization,Sewage treatment plant,Environmental conservation

Introduction

Durgam Cheruvu, also known as Raidurgam Cheruvu, is an 83-acre freshwater lake located near Hyderabad in Telangana, India. Once a secluded haven, it earned the nickname "Secret Lake" due to its hidden location between the upscale areas of Jubilee Hills and Madhapur. The exact age of Durgam Cheruvu is unknown, but its significance stretches back centuries. In recent years, it has undergone a remarkable transformation, evolving from an obscure spot into a popular destination for locals and tourists alike.

The Durgam Cheruvu experience extends beyond its natural beauty. The Durgam Cheruvu Cable Bridge, inaugurated in 2020, serves not only as a convenient route but also as a tourist attraction in its own right. Despite these positive developments, Durgam Cheruvu has faced significant water pollution issues. Untreated sewage and industrial waste have severely impacted its water quality, discouraging recreational activities like swimming and raising concerns about the long-term health of the ecosystem.

The growing popularity of Durgam Cheruvu also presents challenges such as overcrowding, particularly on weekends. Additionally, parking can be difficult due to the surrounding upscale neighborhoods. While beautification efforts are ongoing, some visitors report issues with cleanliness and maintenance, which can detract from the overall experience.

II. Methodology

1. Purpose of the Study

Determining the age of Durgam Cheruvu and understanding the purpose behind its creation can provide valuable insights into Hyderabad's historical development and water management practices. Measuring pollution levels in the lake is crucial for assessing its health and identifying specific contaminants like heavy metals, untreated sewage, or industrial waste. This information is vital for guiding efforts to clean the lake, which could involve setting up proper sewage treatment facilities, implementing stricter waste disposal regulations, or identifying and addressing industrial polluters.

2. Nature of the Study

The data for this research project has been meticulously compiled from a diverse range of credible sources. These include academic journals published online and in print, scholarly books exploring relevant topics, and news articles from esteemed publications such as Telangana Today, Times of India, and The News Minute. Additionally, valuable insights were gleaned from televised reports broadcasted on reputable news channels such as NDTV. By drawing upon such a comprehensive and well-established information base, the research strives to achieve a robust and multifaceted understanding of the subject matter.

3. Analysis

Historical records indicate that Durgam Cheruvu has been a significant water source since the time of the Qutb Shahi dynasty, between 1534 and 1724. The lake is surrounded by sedimentary rocks, suggesting that it and the surrounding lake beds have been present long enough for many layers of sediment to have lithified under water. Originally spanning 150 acres, the lake is geographically situated at a higher elevation than the Golconda Fort area. According to historian Mohammed Shafiullah, during the Mughal siege of Golconda, the entire water needs of the fort were met by Durgam Cheruvu.

Historian Narendra Luther recalls that when he arrived in Hyderabad in late 1958, Banjara Hills was largely uninhabited, with only a dozen houses. He notes that during the 1970s, many people would visit the lake for picnics. This tradition continued until the late 1990s, with residents from nearby villages like Madhapur frequently visiting the lake to catch fish or simply to spend leisure time.

A Timeline of Durgam Cheruvu's Transformation: Balancing Development and Conservation

Early 2000s: Tourism and Emerging Concerns

- **2000:** Durgam Cheruvu was a bustling hub of activity, with families and friends enjoying boating on its clear waters, promoted actively by the Andhra Pradesh government.
- **2001:** The Andhra Pradesh Tourism Development Corporation (APTDC) planned to introduce more boats to meet the growing demand. However, environmentalist K. Purushottam Reddy raised concerns about new residential colonies near the lake, threatening its health. The Andhra Pradesh High Court issued a landmark order to prevent raw sewage from entering the lake and halt further residential construction in the vicinity, emphasizing the protection of Durgam Cheruvu's water quality.

Mid-2000s: Beautification Amidst Deterioration

- **2002:** The tourism department built a bund, cutting off an important channel that fed the lake, posing a significant threat to its ecosystem.
- **2003:** Authorities embarked on a beautification project, including nighttime illumination, a rock garden showcasing ancient geological formations, a floating fountain, and a 2-kilometer walkway. These enhancements aimed to boost tourism despite growing environmental concerns.
- **2004:** Research by the Centre for Economic and Social Studies (CESS) revealed alarming pollution levels, with Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) far exceeding safe limits for aquatic life.
- **2005:** The Hyderabad Urban Development Authority (HUDA) chairperson admitted that untreated sewage from nearby colonies had severely polluted the lake. A proposal for constructing a sewage treatment plant (STP) for Durgam Cheruvu offered hope for its revival.

Late 2000s: Pollution and Interventions

- **2006:** Heavy rains caused the lake to overflow, flooding nearby residential areas and creating health hazards from stagnant sewage.
- **2007:** The inauguration of a five-mega liter per day STP marked a significant step towards addressing pollution. A national seminar on water conservation highlighted the potential for rehabilitating urban lakes like Durgam Cheruvu.
- **2008:** The Andhra Pradesh Industrial Infrastructure Corporation (APIIC) faced allegations of building a road that encroached upon the lake's buffer zone, highlighting ongoing challenges in balancing development and conservation.
- **2009:** Illegal dumping of construction debris by private contractors exacerbated the lake's decline, contributing to its shrinkage and further pollution.

2010s: Renewed Efforts and Ongoing Challenges

- **2010:** The Hyderabad Metropolitan Development Authority (HMDA) announced bio-remediation measures, signaling a shift towards using natural processes to revive the lake.
- **2013:** Despite bio-remediation efforts, untreated sewage continued to flow into the lake, resulting in stagnant, fetid water and posing significant health risks to nearby residents.
- **2014:** Illegal construction further encroached on the lake, shrinking its area to 80-90 acres. The Telangana State Tourism Development Corporation (TSTDC) ceased boating operations due to the lake's poor condition. The Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB) announced plans for a new sewage pipeline, raising environmental concerns.
- **2016:** The Telangana government approved the construction of a hanging bridge across the lake, intended to ease traffic congestion. However, environmentalists and concerned citizens criticized this move, arguing that it could further disrupt the lake's ecosystem and hinder restoration efforts.

Beyond Sewage: Durgam Cheruvu's Cocktail of Contaminants

- Recent studies revealed the lake's heavy contamination with a range of pollutants, including pharmaceuticals, herbicides, fungicides, pesticides, hormones, steroids, and even traces of cocaine. This toxic mix poses serious environmental and health risks, highlighting the urgent need for comprehensive intervention to restore Durgam Cheruvu's health.

The Path Forward

Durgam Cheruvu's transformation from a vibrant tourist spot to a heavily polluted lake underscores the challenges of balancing development and environmental conservation. Despite numerous efforts, the lake continues to face significant threats. Addressing these issues requires a multi-pronged approach, combining infrastructure improvements, natural remediation processes, and stringent enforcement of environmental regulations to protect and revive this valuable urban water body.

Discussion

The early 2000s marked a period of increased tourism and beautification efforts at Durgam Cheruvu. During this time, the lake became a popular destination, with enhanced boating facilities and new attractions like nighttime lighting and a rock garden. However, this period also saw the beginning of significant environmental concerns due to unchecked urbanization and the inflow of sewage into the lake.

In 2004, research conducted by the Centre for Economic and Social Studies (CESS) revealed alarming water quality data, indicating that the lake's health was rapidly deteriorating. This prompted various attempts to address the pollution, including the construction of a sewage treatment plant (STP) and the implementation of bio-remediation measures. Despite these efforts, ongoing challenges such as illegal constructions and dumping practices continued to plague the lake. These activities led to a drastic decline in the lake's water volume and quality.

By 2013, the situation had reached a critical point, with raw sewage flowing into the lake daily and causing severe health hazards for nearby residents. The following year, boating activities were suspended due to the unbearable stench, and a new sewage pipeline was constructed, further disturbing the already fragile ecosystem. Despite these pressing issues, a controversial proposal for a hanging bridge across the lake emerged in 2016, highlighting the persistent conflict between development and environmental protection in the efforts to revive Durgam Cheruvu.

The descent of Durgam Cheruvu from a pristine lake to a heavily polluted body of water is alarming. Recent studies have discovered a vast array of pollutants, including pharmaceuticals, herbicides, and even traces of cocaine. This contamination poses a multifaceted threat. Firstly, the presence of drug metabolites indicates improper disposal practices and raises concerns about the impact on aquatic life and human health. Secondly, the detection of antibiotic metabolites suggests untreated sewage is flowing into the lake, potentially fostering antibiotic-resistant bacteria. Finally, the persistent nature of these pollutants threatens not only the lake itself but also the surrounding groundwater and air quality.

Addressing this crisis requires a comprehensive strategy. Tackling improper disposal of medications, improving wastewater treatment, and potentially employing bioremediation techniques are crucial steps. Unless these issues are addressed swiftly and effectively, Durgam Cheruvu risks becoming a silent killer, jeopardizing the health of the environment and the people who depend on it.

Conclusion

Durgam Cheruvu's story is a cautionary tale of environmental neglect. Once a vibrant lake teeming with life, it now faces an existential threat due to a toxic cocktail of pollutants. The presence of pharmaceuticals, herbicides, and even cocaine in its waters reveals a disturbing reality—a lake choked by improper waste disposal, agricultural runoff, and potential drug use in its vicinity. The long-term implications extend beyond the lake itself, as the persistent nature of these pollutants means they can seep into the groundwater, poisoning this vital

resource. Additionally, under certain conditions, these chemicals can volatilize and transform into airborne contaminants, potentially affecting the health of residents living near the lake.

This contamination creates a vicious cycle, jeopardizing the health of the entire ecosystem, including the lake, the groundwater, and the surrounding environment. The path forward requires a multifaceted approach. Stringent regulations and public awareness campaigns are crucial to address the improper disposal of medications and other household waste. Upgrading wastewater treatment infrastructure to handle pharmaceuticals and other emerging contaminants is essential. Investigating and addressing potential agricultural runoff from surrounding areas is another critical step.

The revival of Durgam Cheruvu necessitates a collaborative effort. Local communities, government agencies, environmental organizations, and research institutions all have a role to play. By working together, they can develop and implement a comprehensive plan to restore the lake's health and prevent it from becoming a silent killer. The future of Durgam Cheruvu hinges on our collective ability to act swiftly and decisively. The lake's fate is not merely an environmental concern; it is a matter of public health and ecological well-being.

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In vitro Antifungal Activity of Leaf Extracts of Mangrove Plant leaves Collected from Gilakaladindi Mangroves, Andhra Pradesh, India

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Abstract: Four mangrove plants *viz., Bruguiera cylindrica*, *Excoecaria agallocha*, *Sesuvium portulacastrum* and *Avicennia marina* were collected from the Mangrove forests of Gilakaladindi, Andhra Pradesh, India. The mangrove plant leaves were first dried and crude extracts were made by using the Soxhlet extraction method. The extracts thus obtained were evaporated by using the rotary evaporator. Different solvents were used in the preparation of the crude extracts which are; Petroleum ether, water, Acetone, and Diethyl ether. These crude extracts were then evaluated for their antifungal activity through Disc Diffusion method and the diameters of the Zone of Inhibition were calculated. An antifungal agent, Streptomycin was used as a positive control. The antifungal activity of the mangrove leaf extracts was tested against four strains of Fungi *viz., Rhizopus oryzae, Mucor indicus, Penicillium citrinum* and *Puccinea sorghi*. In the study, it was found that, *Bruguiera cylindrica* showed highest antifungal activity against *Penicillium* sp. with a Zone of Inhibition (2.1 mm) through Petroleum ether extract and it showed the least the Zone of Inhibition against *Puccinea* sp (0.5 mm) in the aqueous leaf extract. *Exocoecaria agallocha* leaf extract in petroleum ether against *Rhizopus* sp. showed high inhibition (1.8mm) whereas the activity against *Puccinea* sp (0.5mm) shown the least Zone of inhibition. The aqueous extract of *Sesuvium portulacastrum* against *Rhizopus sp.* showed greater Zone of Inhibition (1.7mm), the antifungal activity against *Puccinea* sp showed (0.5mm) Zone of Inhibition. In case of *Avicennia marina* with diethyl ether leaf extract shown the highest Zone of Inhibition (1.4 mm) against *Puccinea* sp*,* and the smallest Zone of Inhibition (0.2 mm) against Acetone leaf extract. Among all the four mangroves, the leaf extracts of *Bruguiera cylindrica* & *Exocoecaria agallocha* has shown the highest Zone of inhibition against the fungi than the rest of the mangrove leaf extracts tested. Scientific research throughout the world has proved the fact that mangrove leaf extracts have great potential against microbial infections.

Keywords: Mangrove leaf extracts, Antifungal activity, Gilakaladindi, Disc Diffusion method, Zone of Inhibition.

Introduction:

The world is endowed with an abundance of naturally available chemical compounds which provide exceptional health benefits to the human beings. They have immense nutritional values and are taken up as extra-nutritional constituents but they are present in smaller quantities in the food that we consume. The impetus driving the scientific research on the health benefits of naturally available plant resources was the unmistakable protective effects shown by the plant-based diet in curing innumerable diseases (Penny M. Kris-Etherton, 2002). Natural plant-based products such as the plant extracts are available for our perusal as standardized extracts or as pure compounds. These compounds are chemically diverse hence, they provide us with an unmatched opportunity to exploit them to design modern drugs to cure a wide variety of diseases (Sasidharan*et. al.,* 2011). These naturally occurring chemical compounds present in the plants also called as "bioactive compounds". They are characterized by the positive or the negative impact that they might potentially have on any biological activity. This is determined by the nature of their chemical structures, their concentration and bioavailability. The bioactive compounds find their uses in the inhibition of gene expression, as antioxidants, in induction or inhibition of enzyme activity, in the inhibition of receptor activities etc., (Agnieszka Zgoła-Grześkowiak and Tomasz Grześkowiak, 2021). Based on their structural and functional differences, the bioactive compounds can be widely categorized as polyphenolic compounds, tocopherols, organosulfur compounds, carotenoids and phytosterols. The presence of bioactive compounds in the food might not alter the nutritional benefits to man on a large scale but they are highly beneficial for the upkeep of his health (Charis M. Galanakis, 2017).

The present study deals with the antifungal activity of selected species of mangroves collected from the coasts of Gilakaladindi, Andhra Pradesh, India. The Indian peninsular coast along with the Andaman and Nicobar Islands is home to a diverse group of mangroves which are specially adapted to live in the harsh brackish water habitats. The mangrove forests are seen near the tropical and the sub-tropical regions of the world along the coasts. They have evolutionarily adapted themselves in such a manner, that they can thrive in varying salinity levels in the soil, are constantly submerged under water so they have pneumatophores which help them in respiration, have succulent leaves which can secrete excess salt when necessary and exhibit viviparity which helps them propagate their future progeny. All these adaptive features have developed evolutionarily due to stress inducing climatic and environmental conditions, so it could be said that they have an abundance of medicinally important bioactive compounds which can help combat several forms of microbial infections and other life-threatening diseases. These compounds can act as precursors of therapeutic drugs or as industrial raw materials. The terpenes and the polyphenols have applications as antifungal, antibacterial, anticancer and antimalarial drugs (Nilesh Lakshman *et. al.,* 2019). These chemical compounds present in the mangroves and their associates can act as a new source to explore and exploit different bioactive compounds unique to them (W. M. Bandaranayake, 2002).

Infectious diseases cause damage and premature death in a number of various organisms all over the world. It has been imminent for mankind to find a cure to combat infectious diseases. Due to the latest boom in scientific exploration and research, efforts are being put in place to find a natural remedy to fight against infectious diseases. Microorganisms have a tendency to multiply quickly and frequently change their genetic makeup. It has now become nearly impossible to cure highly infectious diseases with the help of synthetic antibiotics due to the

constant change in the genetic makeup of the microorganisms. The mangrove plant specimen collected for this study are *Bruguiera cylindrica, Excoecaria agallocha, Sesuvium portulacastrum* and *Avicennia marina*. Many of the mangrove trees found in the world have been used in traditional medication. Several parts of the mangrove plants such as the leaves, stems, roots, barks, flowers and fruits have been traditionally used as medicines to cure diseases such as hypertension, diabetes, gastrointestinal disorders, ulcers, skin diseases and haemorrhages etc. Upon the closer inspection of the medicinal uses of the mangrove plant specimen, several scientists have recorded evidence of their anti-fungal, anti-inflammatory, antioxidant, analgesic, anti-pyretic, anti-bacterial, anti-cancer and antidiabetic properties. (SadeerNabeelah Bibi *et. al.,* 2019). The present study focussing on antifungal activity which is the ability of an antifungal agent in destroying or inhibiting the growth of the fungi, and the compounds which possess this ability to fungicidal compounds respectively. Fungal infections are caused by the Fungi and they are the causative agents behind huge economic losses in health care, agricultural and aquaculture industries. Most of the disease-causing fungi release toxins. For instance, substances like alteneune, altertoxin I, II and III, alternariol and tenuazonic acid are mycotoxins produced by *Alternaria* sp. These toxins are carcinogenic and they have the capacity to inhibit enzyme activity (Escrivá *et. al.,* 2017). Several studies have been made on mangrove plants to prove their antimicrobial, antifungal and anti-helminthic properties owing to the abundance of bioactive compounds present in them.Organic solvent extracts of *B. cylindrica* have shown antifungal action against *Macrophomina phaseolina* and *Cladosporium herbarum* (VarahalaraoVadlpaudi and K. Chandrasekhar Naidu, 2009). Leaf extracts of *S. portulacastrum* have shown antifungal effects against *Asperigillus niger, A. flavus* and *Trichoderma* sp. (Abirami H. and Rameshwari R., 2013). Further exploitation and understanding the significance of the mangrove species would be beneficial to mankind both medically and industrially as well. Plant-based drugs are cheaper alternatives to synthetic drugs and they are easily available in nature so treatment of diseases and their prevention would be easier for those people cannot afford costlier medication.

Materials and Method:

Sample collection and extraction:

Leaves of *Bruguiera cylindrica, Excoecaria agallocha, Sesuvium portulacastrum* and *Avicennia marina* were collected from Gilakaladindi, Andhra Pradesh, India. The plant species collected were sent to the herbaria of Botanical Survey of India (BSI), Hyderabad for their identification. The leaves were cleaned under running tap water to remove the dirt accumulated on them, followed by thorough cleansing with double distilled water and were later shade dried. The shade dried leaves were crushed into a fine powder with the help of a blender and were stored in clean containers at room temperature to avoid deliquescence.

The extracts of the leaves were made with the help of the Soxhlet apparatus by using 10g each of the crushed leaf samples of *Bruguiera cylindrica, Excoecaria agallocha, Sesuvium porulacastrum* and *Avicennia marina* which were mixed with solvents such as acetone, petroleum ether, diethyl ether and double distilled water. These solvents were selected based on their polarity for the extraction of bioactive compounds from the plant specimen by packing them in a Whatman filter paper and placing them in the Soxhlet apparatus. The extracts thus made were carefully filtered using Whatman No. 1 filter paper to help in the removal of solid residues. The samples were then subjected to the rotary evaporator at their respective boiling points to get concentrated crude extracts of acetone, diethyl ether and petroleum ether. The aqueous crude extract was obtained by using the freeze dryer (Onyebuchi and Kavaz, 2020).

***In vitro* antifungal activity:**

The fungi taken for the experiment are *Rhizopus oryzae* (MTCC 2541)*, Mucor indicus* (MTCC 3513)*, Penicillium citrinum* (MTCC 1256)and *Puccinea sorghi*. They were used to study the antifungal properties of various crude extracts of *B. cylindrica, E. agallocha, S. Portulacastrum* and *A. marina.* The active fungi were cultured on Potato Dextrose Agar (PDA) medium so as to obtain sufficient concentration. A loopful of the fungal culture was grown for a period of 36 hours and was further subjected to sub-culturing at room temperature for another 12 hours. Disc diffusion method was used to detect the antifungal potency of the crude extracts. The petriplates were subjected to autoclaving and 10ml of the media was spread uniformly on the petriplates. Each of the selected fungal strain was streaked over the PDA medium uniformly. Wells were made into the agar medium with the help of a sterile cork- borer of 6mm diameter, these were then filled up with 65μL (50 mg/mL) of the plant extract. These plates were then incubated at 28°C for 72 hours. Antifungal agent, Streptomycin was used as a positive control for comparing the potency of *B. cylindrica, E. agallocha, S. portulacastrum* and *A. marina*. The antifungal activity of the crude plant extracts was determined by measuring the diameter of the Zone of Inhibition around the wells (Rastegar and Gozari, 2017), they were recorded in mm.

Results and Discussion:

Antifungal activity:

In the present study, various solvent extracts of *B. cylindrica, E. agallocham, S. portulacastrum* and *A. marina* were studied for their antifungal activity against strains of fungi like *Rhizopus oryzae, Mucor indicus, Penicillium citrinum* and *Puccinea sorghi*.

As per the results, *Bruguiera cylindrica* has shown best antifungal activity in different solvent extracts. The aqueous extract of *B. cylindrica* has shown high antifungal activity at 6.9±0.3 mm against *R. oryzae* and the least antifungal activity was exhibited against *R. oryzae* by diethyl ether leaf extract at 0.3±0.05. It could be revealed that aqueous leaf extracts (DDW) are most effective against the fungal pathogens followed by, acetone (AE) against *P. citrinum* at2.3±0.3 mm and petroleum ether (PE) against *P. citrinum* at 2.1±0.08 mm. The least effective of all extracts is the diethyl ether (DDE). Upon analysing the results of PE leaf extract of *E. agallocha* was the most effective against *P. citrinum* and *R. Oryzae*at 12.0±0.9 mm Zone of Inhibition and 8.0±0.7 mm respectively. The least antifungal activity was exhibited by the DEE leaf extract against *P. sorghi* (0.5±0.08 mm) and *P. citrinum* (0.8±0.02 mm). Moderate results were exhibited by the AE and DDW leaf extracts against *P. sorghi* (6.1±0.4 mm) and *R. oryzae* (6.3±0.1 mm) respectively. The DDW leaf extracts of *S. portulacastrum* have shown the highest Zone of Inhibition against *R. oryzae* at 1.7±0.06 mm. The least antifungal activity was exhibited against *P. sorghi* at 0.8±0.03 mm Zone of Inhibition. Moderate activity was exhibited against *P. citrinum* and *M. indicus*. Upon viewing the results of the DDE leaf extract of *A. marina* was the most effective antifungal agent with antifungal activities against *P. sorghi* (1.4±0.06 mm) and *R. oryzae* (1.1±0.03 mm). It showed moderate Zones of Inhibition against *M. indicus* and *P. citrinum*. The AE leaf extract has shown the least antifungal activity at 0.2±0.02 mm Zone of Inhibition against *P. sorghi* and 0.3±0.01 mm Zone of Inhibition against *R. oryzae*.

Table 3.1a: *B. cylindrica* **leaf extracts antifungal activity (mm)**

Test organism	B. cylindrica				
	Streptomycin	AE	DEE	PE	DDW
Rhizopus oryzae	6.3±1.9	2.0±0.1	0.3±0.05	1.4±0.06	6.9±0.3
Mucor indicus	5.9±1.7	1.5±0.7	0.4±0.1	0.7±0.02	4.9±0.1
Penicillium citrinum	9.3±1.8	2.3±0.3	0.6±0.07	2.1±0.08	6.2±0.2
Puccinea sorghi	7.3±1.3	1.2±0.6	0.4±0.01	0.5±0.03	4.1±0.01

Results are expressed as mean ± standard deviation; n=3

Graph 3.1a: *B. cylindrica* **leaf extracts antifungal activity (mm)**
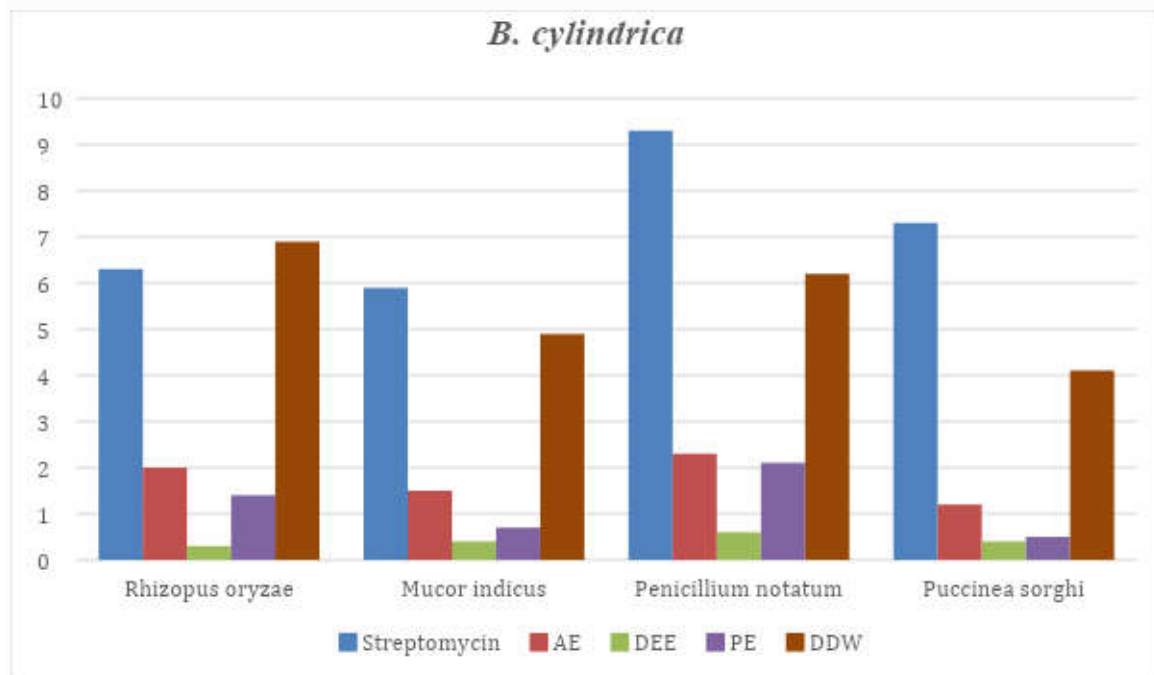
Table 3.1b: *E. agallocha* **leaf extracts antifungal activity (mm)**

Test organism	E. agallocha				
	Streptomycin	**AE**	**DEE**	**PE**	**DDW**
Rhizopus oryzae	6.3±1.9	5.3±0.3	1.3±0.04	8.0±0.7	6.3±0.1
Mucor indicus	5.9±1.7	2.4±0.7	1.7±0.06	7.0±1.1	3.2±0.7
Penicillium citrinum	9.3±1.8	3.3±0.2	0.8±0.02	12.0±0.9	2.4±0.5
Puccinea sorghi	7.3±1.3	6.1±0.4	0.5±0.08	5.0±0.6	2.2±0.4

Results are expressed as mean ± standard deviation; n=3

Graph3.1b: *E. agallocha* **leaf extracts antifungal activity (mm)**
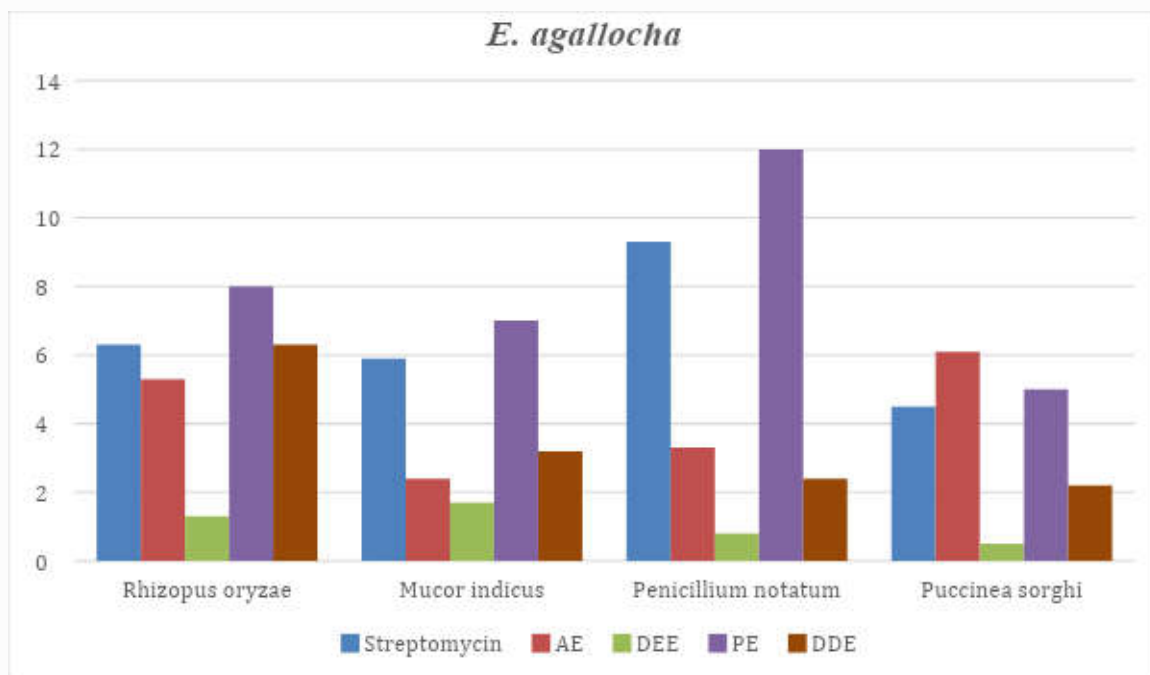
Table 3.1c: *S. portulacastrum* **leaf extracts antifungal activity (mm)**

Test organism	S. portulacastrum				
	Streptomycin	DDW	AE	DE	PE
Rhizopus oryzae	6.3±1.9	1.7±0.06	0.4±0.02	1.6±0.3	1.8±0.6
Mucor indicus	5.9±1.7	1.2±0.8	2.1±05	0.9±0.05	0.9±0.4
Penicillium citrinum	9.3±1.8	1.5±0.6	1.5±0.2	0.3±0.01	0.5±0.08
Puccinea sorghi	7.3±1.3	0.8±0.03	1.8±0.4	1.1±0.4	1.2±0.5

Results are expressed as mean ± standard deviation; n=3

Graph 3.1c: *S. portulacastrum* **leaf extracts antifungal activity (mm)**
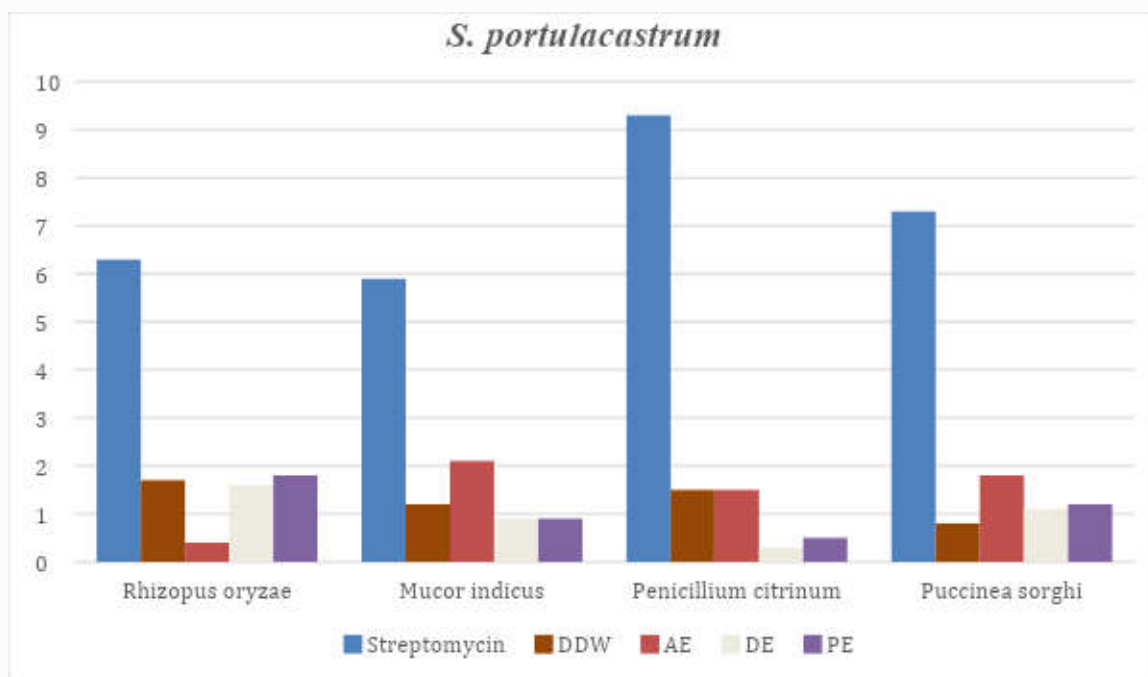
Table 3.1d:*A. marina* **leaf extracts antifungal activity (mm)**

Test organism	A. marina			
	Streptomycin	**AE**	**DEE**	**PE**
Rhizopus oryzae	6.3±1.9	0.3±0.01	1.1±0.3	0.7±0.04
Mucor indicus	5.9±1.7	1.3±0.9	0.8±0.06	1.3±0.2
Penicillium citrinum	9.3±1.8	0.4±0.03	0.5±0.08	1.6±0.6
Puccinea sorghi	7.3±1.3	0.2±0.02	1.4±0.06	0.8±0.05

Results are expressed as mean ± standard deviation; n=3

Graph 3.1d:*A. marina* **leaf extracts antifungal activity (mm)**
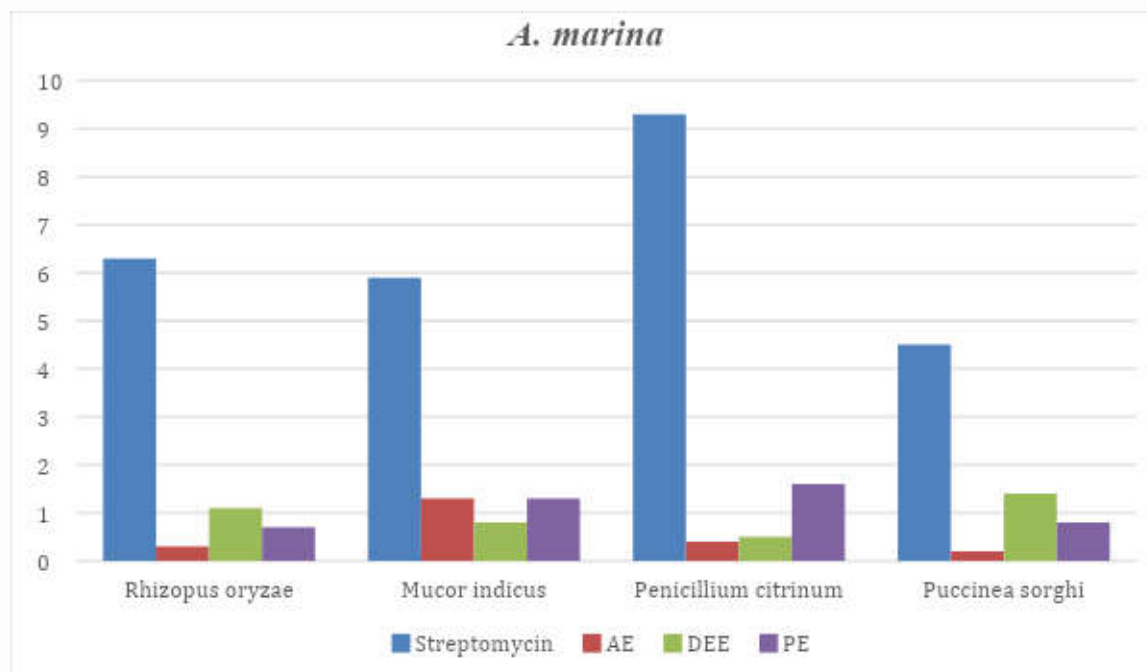
Behbani*et. al.,* (2016) have studied the antifungal activity of the ethanolic and aqueous extracts of the plant *A. marina* against the fungal pathogens *Penicillium digitatum* and *Alternaria citri* and found that the ethanolic extract of the plant were more effective on preventing the growth of *P. digitatum* and *A. citri*. The antifungal potential of the extracts of the leaves, roots and bark of *Bruguiera gymnorrhiza* against the fungi *C. albicans, A. niger* and *A. fumigatus* was studied by Bakshi and Chaudhuri (2014). The results of this study have revealed that *B. gymnorrhiza* was highly effective against *C. albicans* followed by *A. fumigatus*. *A. niger*, on the other hand, exhibited some resistance against the extracts of *B. gymnorrhiza*. Similarly, Rajeshwari and Rao (2016) have worked with several mangrove species like *E. agallocha, R. mucronata, X. granatum* and *A. corniculatum*. They have done phytochemical extraction with the help of solvents like dichloromethane, methanol and hexane followed by screening for antifungal activity against fungal pathogens like *C. albicans, C. neoformes, C. glabrata* and *C. tropicalis*. Their results suggested that methanolic extract was the most effective against all the fungal strains. According to a study done by Kumar and Ahmed (2013),crude extracts of the leaves of *E. agallocha* were effective against the fungi like *Rhizactonia solani, Macrophomina phaseoline, Sclerotium roysii, Fusarium udum* and *Alternaria alternate*. Samuel *et. al.* (2021), have shown that the hexane, methanolic and ethyl acetate crude extracts of plants *S. portulcastrum* and *E. agallocha* were effective against microbes like *Aspergillus flavus, P. aeruginosa* and *E. coli*. The hexane and ethyl acetate crude extracts of both the plants were effective antifungal agents in a dose dependent manner. Martinez-Alvarez (2019), have reported that the mangrove plants belonging to the Rhizophoraceae family have a higher concentration of phenols in them which might be the reason behind the antifungal activity of the mangrove extracts. The leaf extracts of the plants considered for this study *viz., B. cylindrica, E. agallocha, S. portulcastrum* and *A. marina* are also reported to have the presence of phenols in them which might be considered as a plausible reason behind their antifungal activity. Scientific research across the world has supported the fact that the mangrove leaf extracts have great potential for acting as antifungal agents to cure the infectious fungal diseases.

Conclusion:

The aqueous extracts of *B. cylindrica*, *E. agallocha* and *A. marina* were the most effective against almost all the fungal pathogens taken in the present study. The leaf extracts of acetone and petroleum ether had moderate effects on all the fungal strains. Diethyl ether has shown the least antifungal activity against all the fungi. Of all the plant specimen taken for consideration in this study, *B. cylindrica* and *E. agallocha* were the best contenders when it comes to curbing the growth of the fungal pathogens. Extracts of *S. portulcastrum* and *A. marina* have not shown sufficient antifungal activities. The fungus, *Puccinea sorghi* was the most resistant towards all the extracts of the mangroves *B. cylindrica*, *E. agallocha, S. portulacastrum* and *A. marina*.

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Study on air pollution tolerance index in certain plants growing in polluted zone of Hyderabad, India

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Abstract

The pollutants travel through different media, by air and water currents, and also dispersion and deposition. Plants being the primary producers are greatly exposed in and to the environment and basically sharing a link with each being. A simple consideration indicates that there has never been a truly unpolluted atmosphere. The competence of plants against the pollution abuse due to plant tolerance. Plants are examined for their APTI scores for them to be categorized as sensitive, intermediate, and tolerant in order for them to be selected accordingly. For the current study, four plants were selected, are *Bougainvillea spectabilis, Polyalthia longifolia, Terminalia catappa, and Tridax procumbens* collected from the polluted zone of Hyderabad city. Among the selected plants *Bougainvillea spectabilis* and *Polyalthia longifolia* were under the intermediate category whereas *Terminalia catappa*, and *Tridax procumbens* are sensitive to air pollution. Tolerant plant species can also be used in Greenbelt development, as they tend to serve as barriers and act as a sink for air pollutants. Although studies have been carried out on responses of plants to air pollution yet a lacunae exists.

Key words: APTI, Chlorophyll, Ascorbic acid, Tolerance

Introduction

Invasion of the undesired materials and gases to the natural environment is known as the Pollution, and the elements causing pollution are known as the Pollutants. Pollutants can be both natural and a result of manmade activities. It is a global cause and caused globally too (E.C. Halliday 1961). The pollutants travel through air and water currents. Apart from transport the pollutants also move through dispersion and deposition. Developing technology has introduced new forms of pollution into the atmosphere and, on the other hand, town populations have become more intolerant of the types of pollution which they were breathing (E.C.Halliday, 1961).

Urban air pollution is one of the major atmospheric pollution issues that is getting worse with the growing urban population, increasing traffic density and industrialization (Gulia S, 2015). It deteriorates ecological conditions and can be defined as the fluctuation in any atmospheric constituent from the value that would have existed without human activity. Environmental stress, such as air pollution, is among the most important limiting factor for plant productivity and survival. In urban environments, trees play an important role in improving air quality by taking up gases and particles. Plants provide an enormous leaf area for impingement, absorption and accumulation of air pollutants to reduce the pollutant level in the environment (Khureshi S. G. D *et al.*, 2013).

Plants also play their part in monitoring and maintaining the ecological balance by actively participating in the CO_2 and O_2 management. Plants absorb air pollutants such as SO_2, NOx etc. Particulate Matter, including dust settled on the leaves which provides an enormous surface for the accumulation of air pollutants. Increasing population explosion, automobiles, industrialization, urbanization is deteriorating the quality of air in the developing Cities in India. It is necessary to evaluate the status of urban air pollution continuously and to assess its impact on human health and Plants, so that proper initiative measures can be implemented (Shyamala. *et al.*, 2015) Air pollutants affect plant growth adversely (Rao, 2006; Bhatia, 2006; Sodhi, 2007; Horsefall and Spiff 1998; Bhavika Sharma *et al.*, 2017).

The exposure of plants to the polluted regions brings massive damage to their fragile structure and tests their tolerance. The air pollution tolerance index (APTI) as an air pollution monitoring tool is an empirical relation which evaluates the tolerance level of plant species towards air pollution by considering leaf biochemical parameters such as total chlorophyll, ascorbic acid, leaf extract pH, and relative water content (RWC). APTI has been used in studies like green belt development (Shannigrahi *et al.*, 2004), traffic noise reduction (Pathak *et al.*, 2008) and pollution mitigation along roadsides and around industries. (Bhavika *et al.*, 2017). Several studies have shown the impacts of air pollution on plant biochemical parameters, such as the ascorbic acid content, chlorophyll content (Flowers *et al.*, 2007), leaf extract pH (Klumpp *et al.*, 2000) and relative water content (Rao 1977). The use of these different parameters has given conflicting results for the same species (Han *et al.*, 1995). C. O. Ogunkunle *et al.,* (2015) therefore suggested that a single parameter may not provide a clear picture of the pollution-induced changes that may occur in plants. Therefore, The combination of biochemical and physiological parameters gave more reliable result than those of individual parameters. Since, they were computed together in a formulation to obtain

an empirical value signifying the air pollution tolerance index (APTI) of species on the basis of earlier studies (G. Krishnaveni *et al*., 2017).

Various strategies exist for controlling atmospheric pollution, but vegetation provides one of the best natural way of cleaning the atmosphere by providing an enormous leaf area for invasion, absorption and accumulation of air pollutants level in the environment to a various extent. (Varshney 1985; Lui and Ding 2008; Escobedo *et al*., 2008; Das 2010). According to G. S. Mahecha, (2013) plants are very important for determining and maintaining ecological balance by actively participating in the cycling of nutrients and gases like carbon dioxide and oxygen etc., but air pollution can directly affect plants via leaves or indirectly via soil acidification (Steubing *et al*., 1989; Agbaire 2009; Kumar and Nandini 2013). Several contributors agree that air pollutants affect plant growth adversely (Rao 2006; Horsefall 1998). Plants act as the scavengers for air pollution as they are the initial acceptors (Joshi and Swami 2009, Randhi and Reddy 2012). Hence in the recent years urban vegetation became increasingly important not only for social reasons but mostly for affecting local and regional air quality.

The selected zones were polluted zone of Hyderabad, Trees act as air pollution sinks but the better performance comes from the pollution tolerant species (Miria and Khan 2013). By monitoring plants tolerance toward air pollution, they can be screened and can be employed as biological indicators or monitors of air pollution. Then they can be used effectively by planners and green belt developers in managing the urban air pollution. The present study was conducted to evaluate air pollution tolerance index (APTI) in some selected plants as a tool to monitor pollution and green belt development.

Relative water content of leaves is a measurement of its hydration status. According to Barrs (1968), the measurements of water content expressed on a tissue fresh or dry basis have been mostly replaced by measurements based on the maximum amount of water a tissue can hold is referred to as Relative water content The oldest method to check and measurement of water content in plants were based on water content which is expressed as a percentage of either dry or fresh weight. Moreover, the fresh weight is extremely insensitive to small changes in water content. Due to the difficulties faced during measurement of water content in dry and fresh weight leaves, the concept of expressing leaf water content as a percentage of turgid water content came to an existence. Formula for RWC (fresh weight – dry weight)/(turgid weight – dry weight) × 100 (Pieczynski *et al*., 2013).

The study is to determine the APTI scores in plants to know their tolerance/ sensitive level to analyze and compare the air pollution tolerance index of plants and categorize them for biomonitoring.

Materials and Methods

The assessment performed for the comparison of the tolerance values included plants viz: *Bougainvillea spectabilis, Polyalthia longifolia, Terminalia catappa, Tridax procumbens,* From two zones, polluted and control, namely Malakpet (9.5 km from the main campus of St. Ann's College for Women) and Shamshabad (20.2 km from the main campus of St. Ann's College for Women), respectively. Both the zones are 22.5 km apart from each other. The plants from these zones were gathered between 6-7 a.m. in the early morning.

It was observed that no detailed investigation has been taken up on the Biochemical aspects in the plants exposed to Air Pollution. In order for the comparative analysis of the biochemical parameters- Relative water content, Ascorbic acid, total chlorophyll and leaf pH were worked on.

Leaf extract

The fresh leaf materials were taken, washed, before they were transferred separately into different mortar pestle and grinded into a finely thin paste adding a pinch of Calcium carbonate and 10 ml of acetone. And only then the leaf filtrate was taken to perform the further experimentation for the said four biochemical parameters. They were all executed the same day.

Procedure

Relative water content (RWC): RWC (fresh weight – dry weight)/(turgid weight – dry weight) × 100 (Pieczynski et.al 2013) It is the overall quantity of water in a leaf relative to the maximal water a leaf can contain. The leaf materials were kept in petri plates in an oven at 105° C for 2 hrs and then removed to cool them in a desiccator and the weight was recorded (W1 g). Then 5gm of fresh leaf material is Weighed in petri plates and their weights are marked as (W2 g). The petri plates are now kept in the oven for 2hrs at 105°c. and then the leaf material is weighed and noted as (W3 g) . Now the loss of weight determined and the moisture content of the leaf material was calculated.

Ascorbic acid content: It is a component in plants present in an ample amount. It is present in different quantities in plants.1gm of leaf material is taken and ground with mortar and pestle with 10 ml of distilled water. 15 ml of filtrate is pipette out into a conical flask and

Glacial acetic acid is added and titrated against 2,6- D dye until the pale pink colour is observed.

Total chlorophyll content: It absorbs most of the energy from wavelengths of violet-blue and orange-red light and chlorophyll b absorbs light same to chlorophyll a. Fresh leaf material is taken and washed and blotted with blotting paper and then grinded with the help of mortar and pestle by adding a pinch of $CaCO_3$ and add 10 ml of acetone and then centrifuged it for 10 minutes and then transferred it into 100 ml std. flask volume, made mark by adding acetone. The leaf extract is taken into a cuvette and then the O.D is measured in a photometer at 645 nm and 663 nm for chlorophyll pigments 'a' and 'b'.

pH of leaf extract: All the living cells have their own pH and so do the cells present in the leaves of the plants. 1 gm of fresh leaf is taken and ground with the help of mortar and pestle with 10 ml of distilled water.1 ml of leaf extract is pipetted out and diluted with 10 ml distilled water. and 2 to 3 drops of universal indicator is and the colour is observed.

APTI: The air pollution tolerance indices often commonly available plants were determined by the following method by Singh and Rao (1983)

$$\frac{A(T+P) +R}{10}$$

Where, A is Ascorbic acid (mg/g fr. wt), T is Total chlorophyll (mg/g fr. wt), P is Leaf extracts pH and R is Relative water content (RWC) [(%) of the leaves], as mentioned above. The APTI values help to identify the tolerant, intermediate and sensitive plant species.

Results

Relative water content- Relative water content of leaves is a measurement of its hydration status. Poor water content causes defects in the physiology of plants. The values are as **polluted zone (polluted)** -*Tridax procumbens* (27.87) <*Terminalia catappa* (39.32) < *Bougainvillaea spectabilis* (59.74) < *Polyalthia longifolia* (74.21). The values are as shown in Table-1

Table- 1. Relative water content (%) of plant samples selected from polluted zone

S. No	Plant name	RWC
1.	*Bougainvillea spectabilis*	59.74

2.	*Polyalthia longifolia*	74.21
3.	*Terminalia catappa*	39.32
4.	*Tridax procumbens*	27.87

Ascorbic content - This study has revealed that ascorbic acid is lower in significant amounts in plant leaves at the polluted area when compared to the control area. The values shown by *Terminalia catappa* (5.4) < *Tridax procumbens* (8.8) < *Polyalthia longifolia* (8.9) <*Bougainvillea spectabilis* (9.3)

Table- **2**. Ascorbic Acid Content (mg/L)of plant samples selected from polluted zone

S. No	Plant name	Ascorbic acid
1.	*Bougainvillea spectabilis*	9.3
2.	*Polyalthia longifolia*	8.9
3.	*Terminalia catappa*	5.4
4.	*Tridax procumbens*	8.8

Total chlorophyll content - The difference in leaf chlorophyll content can provide information about the physiological conditions and we can see that the chlorophyll content of plants in polluted zones has lower levels than compared to the controlled zone. The chlorophyll content values present in plants from polluted zone are, *Tridax procumbens* (0.146) <*Terminalia catappa* (0.155) <*Polyalthia longifolia* (0.225) <*Bougainvillaea spectabilis* (0.296). The values are as shown in the

Table- 3. Chlorophyll Content (mg/gfw)of plant samples selected from polluted zone

S. No	Plant name	Total chlorophyll (mg/gfw)
1.	*Bougainvillea spectabilis*	0.296
2.	*Polyalthia longifolia*	0.225
3.	*Terminalia catappa*	0.155
4.	*Tridax procumbens*	0.146

pH of leaf extract:

pH content determines the ion concentration and correlation of sensitivity to plants and it also determines if the leaf is acidic or basic in nature and its intensity. Photosynthesis is highly

dependent on the pH of leaves. The increasing values of pH can be seen as follows, _Bougainvillea_(6.5) <_Tridax procumbens_ (6.5) < _Polyalthia longifolia_ (7) < _Terminalia catappa_ (7) for polluted zone. The values are as shown in the Table - 4

Table- 4. pH of plant samples selected from polluted zone

S. No.	Plant name	pH of the leaf extract
1.	_Bougainvillea spectabilis_	6.5
2.	_Polyalthia longifolia_	7
3.	_Terminalia catappa_	7
4.	_Tridax procumbens_	6.5

Table- 5 APTI of selected plants from polluted zones

Plant name	APTI	Category
Bougainvillea spectabilis	12.28	Intermediate
Polyalthia longifolia	13.8	Intermediate
Terminalia catappa	7.79	sensitive
Tridax procumbens	8.6	sensitive

Discussion

Urbanization has led to deforestation and changing of forest land to agricultural lands, the development of cities has increased the rate of pollution which has caused many different types of problems towards the plants apart from deforestation, the physiology is also affected due the increasing pollution. Air pollution injury to plants can be evident in several ways. Injury to foliage may be visible in a short time and appear as necrotic lesions (dead tissue), or it can develop slowly as a yellowing or chlorosis of the leaf. APTI index shows the capability of a plant to fight against air pollution. The values are as shown in Table -5. Low-index plants exhibit susceptibility to air pollution. Plants are categorized as sensitive (<12), intermediate (13–20), and tolerant (>20) based on their APTI score. Plants are divided into three categories based on their APTI value: sensitive (<12), intermediate (13–20), and tolerant (>20) (Flowers - 2007).

This study suggests that _polyalthia longifolia_ and _Bougainvillea spectabilis_ fall under intermediate category of APTI index.

From the above results we have seen how much of impact pollution has on the water content in plants, Availability of water in plant cells associated with the protoplasmic permeability of cells and thus a loss in water content and nutrients from the cells resulted in senescence of leaf in very early stage of plant life (Masuch G et.al.1998, Agarwal S *et al*., 1997). One study has indicated that plants with higher RWC would have greater drought resistance, so it can be concluded that high water content in plants may lead the plant species to be tolerant (Dedio W et.al. 1975). So in this study we can see that *Polyalthia longifolia* has higher RWC value compared to the other plant-74.21% and all the selected plants from the polluted zone have high RWC values, this proves that the plants have shown resistance to the pollution.

Ascorbic acid content in the selected plant species is lower in polluted zone when compared with the controlled zone. Ascorbic acid plays a role in the cell wall synthesis, defense and cell division (Conklin PL. *et al*., 2001). It is also a strong reducer and plays an important role in photosynthetic carbon fixation (Pasqualini S et.al.2001). Moreover, its high level in plants indicated a high tolerance level of plant species against pollutions and its lower values rank the plants in a sensitive category against air pollution (Chaudhary CS *et al*.,1977, Varshney SRK *et al*., 1984). Thus, the decrease in the ascorbic acid content of plant species in polluted zones may be due to the continuous exposure to pollution.

Photosynthetic processes of plants mainly depend upon the chlorophyll content and development of biomass; it varies from plant to plant due to leaf age, biotic, abiotic conditions and pollution levels (Katiyar V *et al*., 2001). The disintegration of these pigments in plants exposed to pollution may occur due to atmospheric pollutants (Ninave SY *et al*., 2001). As the air pollutant directly enters in the tissues through stomata, causes partial denaturation of the chloroplast, and decreases the pigment content in the cells of polluted leaves. Degradation of photosynthetic pigments has been widely used as an indicator of air pollution (Ninave SY et.al 2001). So the lower levels of pollution indicates the higher levels of air pollution.

The pH values obtained in the result shows that the pH range in the polluted zone is acidic to neutral. The plants with high sensitivity to SO_2 and NO_2 close the stomata faster when they were exposed to pollutants (Thambavani S *et.al*., 2012). pH content determines the ion concentration and correlation of sensitivity to plants and it also determines whether the leaf is acidic or basic or alkaline in nature and its intensity photosynthesis is highly dependent on the pH of leaves. The lower pH values help us to maintain the physiological condition of

plants. The higher pH ranges are also causing low photosynthesis or reduce the photosynthetic process.

Conclusion

This study disclosed that the plants vary in their sensitivity from species to species, having different degrees of tolerance. Plants with high resistance can be considered and planted to lessen the pollution while those with low APTI are used to measure the pollution levels. The study is a step towards monitoring and mitigating the enormously growing pollution. This method of calculating the APTI determining all the four biochemical parameters separately, is cost effective and hence the most used and favored. By the observations in this study, we can say that plants have the ability to serve as excellent quantitative and qualitative indices of pollution, fighting against the air Pollution impacts. The tolerant plant species can help in subduing the threatening health impacts from continuous exposure to air pollutants along with regulating ecosystem services and thus bettering the ecology. Tolerant plant species can also be used in Greenbelt development, as they tend to serve as barriers and act as a sink for air pollutants. They can be used for avenue plantation on the roadsides and in highly polluted areas like industrial areas or the busy roads of the city to control the pollution levels. can be used as the bioindicator to indicate the pollution levels in a particular area and can help to mitigate air pollution

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Changes in Chlorophyll content in certain ornamental plants growing in polluted region

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Abstract

Chlorophyll, the green pigment found in plants, plays a fundamental role in photosynthesis, the process by which plants convert light energy into chemical energy. Understanding chlorophyll content is crucial for assessing plant health, photosynthetic efficiency, and environmental responses. The aim of the present investigation is to understand effect of air pollution on the photosynthetic pigment content. Chlorophyll assessment and the integration of chlorophyll data with other physiological parameters to gain a comprehensive understanding of plant health and productivity. The result showed a decline in the chlorophyll content in certain selected plants growing in the polluted regions giving an insight tounderstand plant health, photosynthetic efficiency, responses to environmental stressors.

Keywords – Chlorophylls, Photosynthesis, Air pollution, Oxidative stress

Introduction

Chlorophyll is a necessary pigment for photosynthesis as it absorbs the light energy from the sun and converts it into chemical energy in the plant. Chlorophylls are classified into Chlorophyll a,b,c and d. Chlorophyll is the marked photosynthetic pigment in higher plants, algae and cyanobacteria. It absorbs red light in the visible region at 680 nm. Chlorophyll b also absorbs red light in the visible region at 660 nm. Chlorophyll c is well described in microbes, algae and absorbs light in the red region (450-640 nm). However, chlorophyll d is reported in cyanobacteria whose habitats are areas that lack visible light. Hence, they absorb light in the IR region between 700 and 730nm.

Generally, the standard ratio of the chlorophyll a and b in higher plants is approximately 3:1 ratio. However, it has been identified that this ratio of chlorophyll a to chlorophyll b varies depending on genetic and environmental conditions. Having more chlorophyll B in chloroplasts

of cells is adaptive factor.Chlorophyll 'a' allows plants to photosynthesize, use sunlight to convert simple molecules into organic compounds and is the predominant type found in green plants and algae. Chlorophyll 'b' helps in photosynthesis by absorbing light energy.

Air pollution has become a serious challenge in, both developed and developing countries, with multiple emission sources continuously adding particulates and gaseous pollutants to the environment (Barwise and Kumar, 2020). Certain gaseous pollutants like So_2, No_x, Co, and Co_2 have severe effect on the plant health. Sulphur dioxide (SO_2) is a gaseous air pollutant that can have detrimental effects on chlorophyll, the green pigment responsible for photosynthesis in plants. Sulphur dioxide (SO_2) is one of the most common harmful air pollutants (Li. Long, Yi. Huilan 2012). SO_2 can directly interact with chlorophyll molecules. This interaction can lead to structural changes in chlorophyll, affecting its ability to absorb light effectively. SO_2 exposure can disrupt the electron transport chain, a series of protein complexes in the thylakoid membrane of chloroplasts. This chain plays a vital role in converting light energy into chemical energy during photosynthesis. Interference with this process can reduce the efficiency of photosynthesis. SO2 can be absorbed by plant tissues and converted into sulphite ions. Sulphite ions can further interfere with the photosynthetic process by inhibiting enzymes involved in chlorophyll biosynthesis and degradation(Padhi et al., 2013). Exposure. ROS, such as superoxide radicals and hydrogen peroxide, can cause oxidative stress. This stress damages cellular components, including chlorophyll molecules, contributing to a decline in chlorophyll content. can lead to the production of reactive oxygen species (ROS) within plant cells (Lihong Li, Huilan Yi 2012). SO2induced oxidative stress can trigger the breakdown of chlorophyll molecules (Malhotra 2006). high doses can lead to leaf chlorosis and necrosis, growth inhibition and plant death (Agrawal *et al*., 2003).Cumulative effects of SO2 on chlorophyll and photosynthesis can result in stunted growth, reduced biomass, and lower crop yields (Padhi et al., 2013). Plants exposed to elevated levels of SO2 may exhibit overall poor health and diminished productivity.

CO indirectly affect plants and their chlorophyll content through its influence on overall plant metabolism and cellular processes. CO can inhibit cytochrome oxidase, an enzyme involved in the electron transport chain of cellular respiration (Sowbiya 2014). This inhibition may lead to a decrease in ATP production, affecting energy availability for various cellular processes,

including those related to chlorophyll biosynthesis. Elevated levels of CO can induce stress responses in plants increase production of ROS that can attack bio macromolecules and results in oxidative damage to nucleic acids, proteins and lipids (Mittler. , 2004; Afzal · 2023) impact chlorophyll biosynthesis and photosynthetic activity. Stress-induced alterations in chlorophyll content can manifest as changes in leaf colour or morphology. Although CO does not directly interact with chlorophyll, changes in cellular processes influenced by CO can potentially affect photosynthetic efficiency. Reductions in energy availability and metabolic disruptions may lead to suboptimal conditions for chlorophyllmediated photosynthesis.

NO_2 may inhibit the fixation of carbon dioxide in the dark reaction by competing with carbon assimilation for NADPH produced by the photoreaction, thereby reducing the photosynthetic rate. (Hill 1970; Srivastava 1975; Sabaratnam et al. 1988). Nitrogen oxides (NOx), which include nitric oxide (NO) and nitrogen dioxide (NO2), can have complex effects on chlorophyll and plant physiology (M Takahashi · 2014). Nitric oxide (NO) can act as a signalling molecule in plants. It plays a role in various physiological processes, including seed germination, root development, and responses to stress (Sun , 2021). NO can also be involved in the regulation of stomatal closure and opening, affecting gas exchange and water balance in leaves. Exposure to elevated levels of NO2 can cause chlorosis, leading to a reduction in chlorophyll content (Muneer, 2013). high concentrations of NO_2 can lead to excessive accumulations of nitrite (NO_2^-) (Okano et al., 1986) and cell acidification (Schmutz, 1995), which lead to negative responses such as the generation of reactive oxygen species (ROS) and inhibition of both N assimilation and plant growth, further causing acute damage to leaves, whole-plant chlorosis or even death. While NO can play a role in signalling pathways and has some positive impacts, NO2, in higher concentrations, is generally considered a pollutant with detrimental effects on plants.

The aim of the present investigation is to understand the effect of air pollution on the content of photosynthetic pigments in the selected plants growing in highly polluted zones and to relate the study to plant health, photosynthetic efficiency of plant responses to environmental stressors.

Materials And Method:

The Plants *Ixora Coccinea,Nerium Oleander,Bougainvillea Glabra,Hibiscus rosa sinensis,* *Tecoma stans*for the Study of chlorophyll pigmentswere collected from polluted and control areas in the early hours and brought to the lab in an ice box. The leaves were washed with the distilled water thoroughly for further use.

Estimation of chlorophylls was done as per Arnon (1949) method.

0.2gof the freshleaf material was taken in motor and pestleand macerated adding 10 ml of 80% acetone into a fine paste. A Pinch of calcium carbonate was added while grinding. The aliquot was collected into a centrifuge tube and all the samples were centrifuged at 3000 rmp for 20 minutes. After centrifugation the supernatant was collected and volume was made up to 25 ml and the optical density of the sample was taken at 663 and 645 to estimate the chlorophyll content.

Results and Discussion

Fig. 1. Chlorophyll 'a', 'b', and Total chlorophyll in the plants collected from control zone
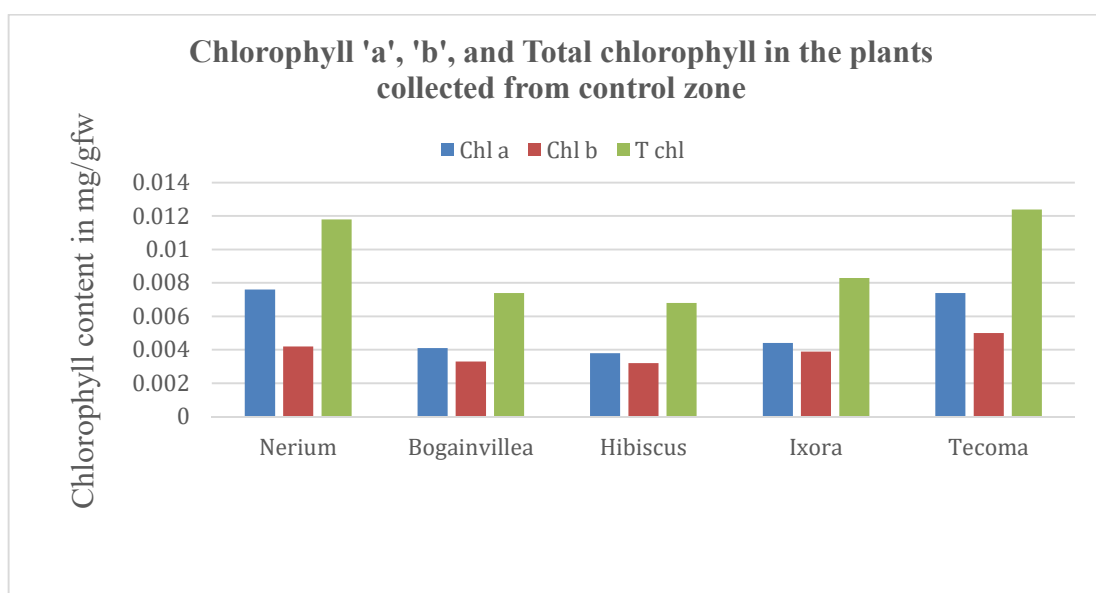
Fig.2. Chlorophyll 'a', 'b', and Total chlorophyll in the plants collected from polluted zone
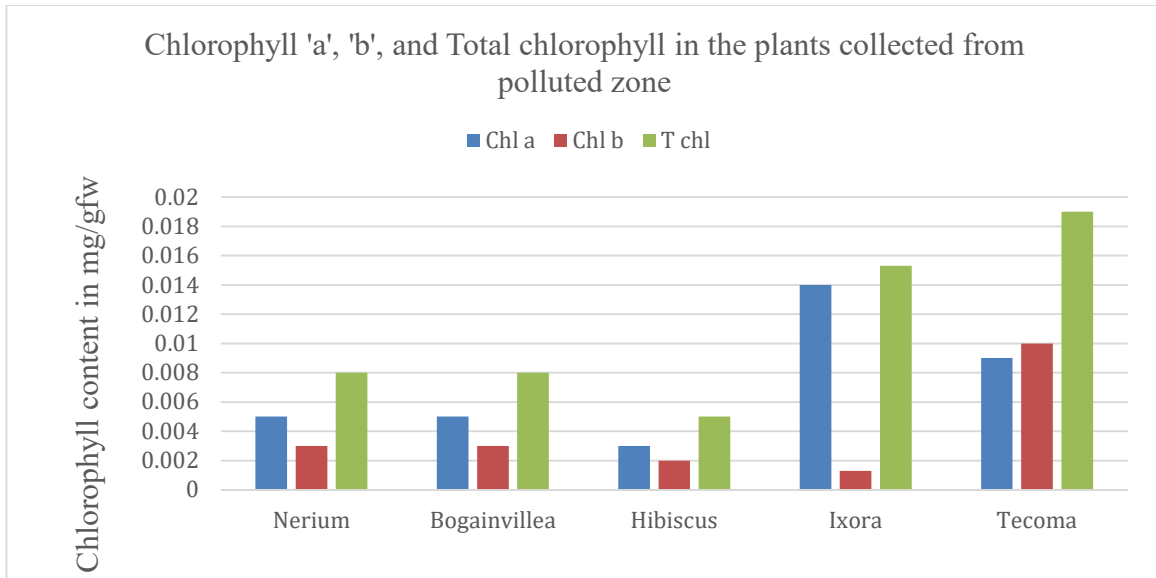
Fig.3.Chlorophyll a/b ratioin the selected plants from control and Polluted zones
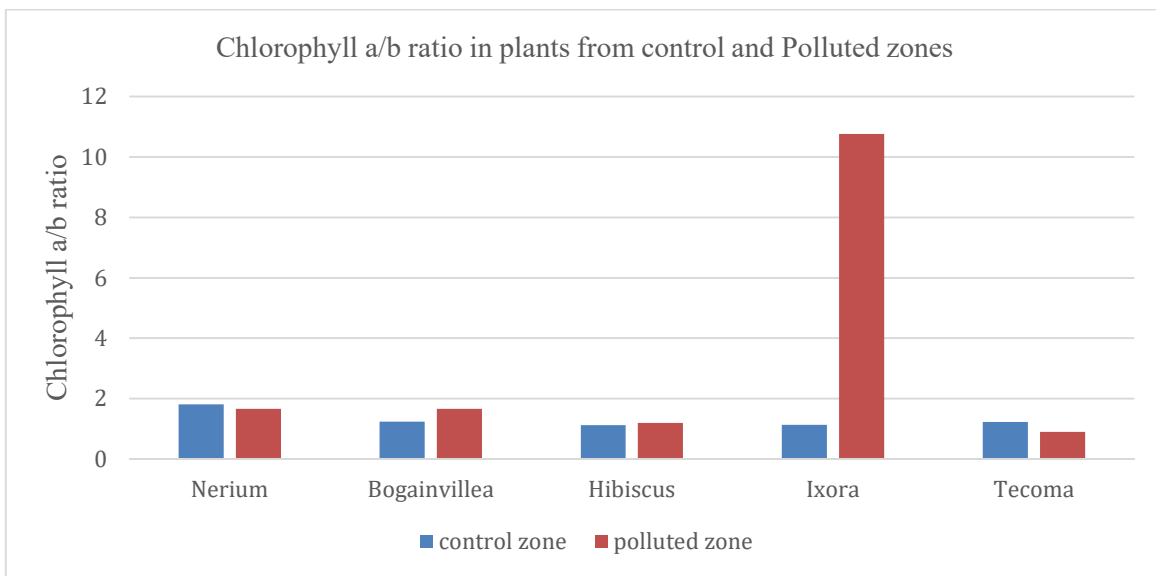
Result & Discussion

In the present investigation a decrease in chlorophyll a, b & total chlorophyll was observed in the leaves collected from polluted zone (Fig.2.) as compared to the samples from control zone (Fig.1.). A decrease of 70% in chlorophyll a, 23% in chlorophyll b was noted in in Nerium leaves.

In Bougainville plants samples collected from the polluted zones showed a slight increase in chlorophyll a and total chlorophyll content as compared to the control plants. An increase of 25% in chlorophyll a and 14% in total chlorophyll content was noted

In hibiscus plant a decrease in the chlorophyll contain was observed in the leaf collected from polluted zones as compared to the control. A decrease of 33% in chlorophyll b and 28% in total chlorophyll was observed

Ixora plants showed an increase in chlorophyll 'a' and total chlorophyll in the leaf collected from polluted zones as compared to the control. 250% Increase in chlorophyll 'a' and 237% in total chlorophyll contained was recorded.

In Tecoma chlorophyll 'a' chlorophyll 'b' and total chlorophyll was observed to be more in the plant collected from the polluted zones as compared to the controlled and increase of 28% in chlorophyll a , 100% in chlorophyll b and 58% and total chlorophyll.

DISCUSSION

The result of the study shows that in total chlorophyll increasing in the leaves of Bougainville, Tecoma and Ixora collected from the polluted zones.This increase could be increased concentration of carbon dioxide and high temperature in a polluted region resulting in the enhancement of the pigment. However, a reduction in the chlorophyll content was reported in Hibiscus and Nerium plants growing in the polluted zones. The reduction and chlorophyll content could be due to the damage caused by air pollution, chlorophyll pigment under stress may undergo several photochemical reactions like oxidation reduction and reversible activity (Talebzadeh, 2022). Oxides of nitrogen, sulphur and fly-ash are the major proportions for the gaseous and particulate emissions from industries and automobile. The exposure of these pollutants to theleaves causes a reduction in the concentration of their photosynthetic pigment's (Giri et al., 2013). The photosynthetic pigments are the most likely to be damaged by air pollution. Chlorophyll pigments exist in highly organized state, and under stress they may undergo several photochemical reactions such as oxidation, reduction, pheophytinisation and reversible bleaching (Puckett et al., 1973). Chlorophyll a/b ratio provides a degree of tree tolerance index, and higher plant species typically produce more Chlorophyll 'a' than Chlorophyll 'b' (Turkyilmaz, 2018). A high ratio is an indication of better air pollution tolerance, and the low ratio indicates sensitivity(Kondo N et al., 1980).It is clear that the air pollution

caused by industries and automobile smoke are operative ecological factor causing deterioration in the quality of our environment (Shah et al., 1989).

Conclusion

Chlorophyll assessment and the integration of chlorophyll content with other physiological parameters helps to gain a comprehensive understanding of plant health and productivity. These findings underscore the profound impact of air pollution on plant physiology, highlighting the need for environmental protection and effective urban planning to alleviate the damaging effect on plant health and ecosystem dynamics. and other physiological processes. Additionally, comparing chlorophyll content among different plants can provide insights into the effects of various factors on plant growth and development and helps to identify the tolerant plants.The present studies showsthat environmental stress is directly proportional to the energy production in the plant due to decrease in chlorophyll content.

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Comparative study of Thiamine and Ascorbic acid in selected leafy vegetables

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Abstract

Leafy vegetables, commonly consumed daily in food are one of the major sources of vitamins. These vegetables also contain an abundance of carotenoids, antioxidants that protect cells and play roles in blocking the early stages of cancer. They also contain high levels of fiber, iron, magnesium, potassium and calcium. Furthermore, greens have very little carbohydrates, sodium and cholesterol. The dark greens supply a significant amount of folate, ascorbic acid, vitamin B that promotes heart health and helps prevent certain birth defects. Eating leafy vegetables is vital to a healthy, balanced diet. It is very beneficial to determine the concentration level of individual vitamins present in leafy vegetables for the regulation of a balanced diet. In this study, we aimed to quantify the content of Ascorbic Acid (Vitamin C) and Thiamine (Vitamin B_1) in five different green leafy vegetables: *Spinacia oleracea* (spinach), *Amaranthus cruentus* (amaranth), *Trigonella foenum-graecum* (fenugreek), *Basella alba* (Malabar spinach), and *Coriandrum sativum* (coriander), utilizing a titration method with 5% DCIP for Ascorbic Acid and alkalimetry method for Thiamine. Our preliminary findings suggest variability in the vitamin content among the tested leafy vegetables. This research underscores the importance of incorporating a variety of leafy vegetables into the diet and highlights the need for standardized nutrient quantification methods. The highest and lowest concentration of vitamin B_1 and vitamin C was observed in *Trigonella foenum-graecum* (fenugreek), *Spinacia oleracea* (spinach) and *Basella alba* (Bachala), *Amaranthus cruentus* (Amaranth) respectively.

Keywords: *Spinacia oleracea* (spinach), *Coriandrum sativm* (coriander), *Amaranthus cruentus* (amaranth), *Trigonella foenum-graecum* (Fenugreek), *Basella alba* (bachala), Ascorbic Acid (vitamin c), Thiamine (Vitamin B_1).

Introduction

Vitamins are indispensable micronutrients that play critical roles in numerous biological processes essential for maintaining health and preventing diseases. Unlike macronutrients, such as carbohydrates, proteins, and fats, which serve as energy sources and building blocks for the body, vitamins facilitate a myriad of biochemical reactions without being consumed themselves. They are classified into two categories: fat-soluble vitamins (A, D, E, and K), which can be stored in the body's fatty tissues, and water-soluble vitamins (C and the B-vitamins), which must be regularly replenished due to their rapid excretion from the body.

Ascorbic Acid, commonly known as Vitamin C, is a water-soluble vitamin renowned for its antioxidant properties and its role in collagen synthesis (Smirnoff, N., & Wheeler, G. L. (2000). Ascorbic acid in plants: Biosynthesis and function. Critical Reviews in Biochemistry and Molecular Biology, 35(4), 291-314).Collagen, a structural protein, is vital for the health and repair of tissues, making Ascorbic Acid crucial for wound healing, skin health, and the maintenance of bones and teeth. Beyond its structural roles, Vit- C enhances the absorption of iron from plant-based foods, contributing to the prevention of iron-deficiency anemia, particularly significant in vegetarian and vegan diets. Its deficiency, historically known as scurvy, characterized by bleeding gums, weakness, and bruising, underscores the essential nature of Ascorbic Acid in the diet.

Ascorbic Acid, beyond its well-known roles in human health, plays crucial roles in plant health and development (Padayatty, S. J., & Levine, M. (2016). Vitamin C: The known and the unknown and Goldilocks. Oral Diseases, 22(6), 463-493) .In plants, it functions as a major antioxidant, protecting the plant cells from oxidative stress caused by various environmental pressures such as UV radiation, temperature extremes, and drought. Its role in photosynthesis and the synthesis of plant hormones underscores the interconnectedness of Vitamin C's functions across different biological kingdoms.

Thiamine plays a pivotal role in energy metabolism, acting as a coenzyme in the catabolism of sugars and amino acids. This Vit - B1 is crucial for the proper function of the cardiovascular and nervous systems (Bettendorff, L., & Wins, P. (2013). Thiamine: A key molecule in health and disease. Metabolic Brain Disease, 28(2), 227-2370). It aids in the production of the neurotransmitter acetylcholine, which is involved in muscle contraction and heart function

(Rapala-Kozik, M. (2011). Thiamine (vitamin B1): Metabolism, functions and deficiency. Pharmacological Reports, 63(4), 851-858). Thiamine's deficiency leads to beriberi, manifesting in either wet (cardiovascular) or dry (neurological) forms, and Wernicke-Korsakoff syndrome, a severe neurological disorder often associated with alcoholism.

Research has shown that Thiamine can also enhance plant resistance to biotic and abiotic stresses, including pathogens and physical stressors like salinity and drought. This protective role is attributed to Thiamine's ability to induce systemic acquired resistance, a plant-wide response to stress that involves the activation of a variety of defensive pathways. By boosting Thiamine levels, plants can better withstand environmental challenges, leading to implications for sustainable agriculture practices focused on reducing chemical inputs.

Green leafy vegetables represent a diverse group of plants that are rich sources of vitamins, minerals, and dietary fiber. These vegetables, including spinach, kale, Swiss chard, and collard greens, are not only low in calories but also high in folate, Vitamin K, calcium, iron, and phytochemicals with antioxidant properties. Their inclusion in the diet supports a multitude of health benefits, ranging from reduced risk of chronic diseases to improved digestive health and weight management.The content of Ascorbic Acid and Thiamine in green leafy vegetables can vary significantly depending on the species, cultivar, and environmental conditions under which they are grown. Factors such as soil quality, exposure to sunlight, and water availability can influence the nutritional composition of these plants. Moreover, agricultural practices, including the use of fertilizers and pesticides, also play a role in determining the final vitamin content of these vegetables.

The nutritional quality of green leafy vegetables, particularly in terms of their Vitamin C and B1 content, can be significantly influenced by agricultural practices. Organic farming, for instance, often emphasizes soil health and biodiversity, which can lead to higher levels of certain nutrients in crops. Crop rotation, intercropping, and the use of compost and organic fertilizers are practices that not only support sustainable agriculture but also can enhance the nutritional profile of green leafy vegetables. Advancements in agricultural technology, including controlled environment agriculture (CEA), offer opportunities to optimize the growth conditions of plants, potentially maximizing their nutritional value. By precisely controlling light, temperature, humidity, and CO_2

levels, CEA can increase the concentration of vitamins and other beneficial phytochemicals in green leafy vegetables.

To maximize the health benefits of green leafy vegetables, concerted efforts from policymakers, educators, and community leaders are necessary. Nutritional guidelines and policies that promote the consumption of a variety of vegetables can encourage healthier eating patterns. School and community programs that educate about the benefits of vegetable consumption and provide hands-on experiences with gardening can foster a greater appreciation for these nutritious foods.Integrating traditional knowledge with scientific research in the cultivation and use of green leafy vegetables can also play a role in preserving biodiversity and cultural heritage while addressing nutritional needs. Collaborative efforts that bridge agricultural development, nutrition education, and environmental sustainability are essential for promoting the growth and consumption of green leafy vegetables worldwide.

to its antioxidant properties, are areas of ongoing research. The plant's adaptability to cooler climates and nutritional versatility make it a staple in various culinary traditions globally.

Materials and methods

Chemicals required:

Standard Thiamine

Blue thymol brom indicator (0.04%)

Standard ascorbic acid

NaOH(0.1N)

Oxalic acid solution (4%)

DCIP Solution (5%)

Sodium bicarbonate

2.2.1 Selection and collection of leafy vegetables:

Leafy Vegetables for analysis of vitamin B1 and vit C content was purchased from Mehdipatnam Market and brought to the laboratory. Washed thoroughly with water and dried using blotting paper. Each green leafy vegetable sample (spinach, amaranth, fenugreek, bachala, and coriander)

is prepared by macerating 1 gram of the vegetable with 10ml distilled water using a mortar and pestle. The macerate is then filtered using Whatman filter paper to obtain a clear extract.

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Thiamine (vitamin B_1)

For the blank titration, 1 ml of the standard thiamine solution was added to a conical flask along with 3 drops of thymol blue indicator. The mixture is titrated until a light blue (end point) is observed.Sample Titration for Thiamine: 1 ml of each vegetable sample extract was added to separate conical flasks, along with 3 drops of thymol blue indicator. Each sample was titrated, and the endpoint is noted when the solution turns light blue.

Ascorbic Acid (vitamin c)

For the blank titration, 0.5 ml of the standard ascorbic acid solution is mixed with 1 ml of oxalic acid. The mixture is titrated against the DCIP solution until a onion peel pink end point is observed. Sample Titration for Ascorbic Acid: 0.5 ml of each vegetable sample extract is mixed with 1 ml of oxalic acid in separate conical flasks. Each sample is titrated against the DCIP solution, noting the end point when the solution turns onion peel pink.

Results and Discussion

In selected leafy vegetables concentration of Thiamine (vitamin B_1) in *Spinacia oleracea* (spinach) 0.001mg/g, *Amaranthus cruentus* (Amaranthus) 0.0014mg/g, *Coriandrum sativum* (Coriander) 0.0016mg/g, *Trigonella foenum graecum* (Fenugreek) 0.0022mg/g, *Basella alba* (Bachala) 0.0018mg/g and concentration of Ascorbic acid in *Spinacia oleracea* (spinach) 7.1mg/g, *Coriandrum sativum* (coriander) 8mg/g, *Amaranthus cruentus* (Amaranthus) 4.1 mg/g, *Trigonella foenum graecum* (Fenugreek) 8mg/g, *Basella alba* (Bachala) 10.6mg/g.

This research article has extensively explored the critical roles of vitamins, particularly Ascorbic Acid (Vitamin C) and Thiamine (Vitamin B_1), in both human and plant health. The study underscores the indispensable nature of these vitamins in facilitating essential biochemical reactions, supporting structural integrity, and enhancing resistance to environmental stresses. The investigation into the vitamin content of green leafy vegetables, including spinach, amaranth, fenugreek, bachala, and coriander, has provided valuable insights into the nutritional benefits these plants offer and the factors influencing their vitamin composition.
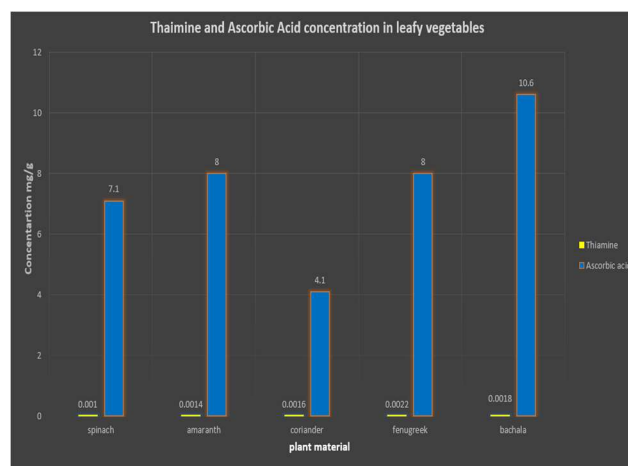
Graph 1: Thiamine and Ascorbic acid concentration in selected leafy vegetables

Our findings have implications for both public health and agricultural practices. The study reinforces the importance of including a variety of green leafy vegetables in diets to combat micronutrient deficiencies and promote overall health. Furthermore, the research supports the adoption of sustainable agricultural practices, such as organic farming and controlled environment agriculture, to enhance the nutritional quality of crops while minimizing environmental impact.

The study also opens avenues for future research, particularly in optimizing agricultural practices to increase the bioavailability of essential vitamins and exploring the potential of these vegetables in mitigating chronic diseases through diet. Collaborative efforts between agricultural scientists, nutritionists, and policymakers are crucial to translate these findings into strategies that promote

the cultivation and consumption of nutritionally rich green leafy vegetables, contributing to global health and food secure

Conclusion

The research article, focusing on the nutritional analysis and health implications of green leafy vegetables, has explored the critical roles of vitamins, particularly Ascorbic Acid (Vitamin C) and Thiamine (Vitamin B1), in both human and plant health. Through the study of *Spinacia oleracea* (spinach), *Amaranthus cruentus* (amaranth), *Trigonella foenum-graecum* (fenugreek), *Basella alba* (Malabar spinach), and *Coriandrum sativum* (coriander), we have uncovered the intrinsic value these plants hold in contributing to a balanced diet and addressing nutritional deficiencies.

The investigation highlighted the antioxidant properties of Ascorbic Acid, essential for collagen synthesis and iron absorption, and the pivotal role of Thiamine in energy metabolism and neurological function. These findings underscore the importance of green leafy vegetables in preventing diseases related to vitamin deficiencies, such as scurvy and beriberi, and in promoting overall health and well-being.

Our research also delved into the agricultural practices that influence the nutritional content of these vegetables, revealing that organic farming and controlled environment agriculture (CEA) can enhance the levels of essential nutrients. This insight is crucial for developing sustainable agriculture practices that not only support environmental health but also improve the nutritional quality of food crops.

Furthermore, the study has demonstrated the global significance of green leafy vegetables in nutrition and sustainable diets. In regions facing malnutrition and micronutrient deficiencies, these vegetables offer a vital source of essential vitamins and minerals. The promotion of green leafy vegetables, through nutritional education and policies that support their production and consumption, is therefore essential for improving public health outcomes worldwide. the indispensable role of green leafy vegetables in human nutrition and plant health. The enhanced understanding of their nutritional benefits, coupled with advances in agricultural practices, paves the way for innovative strategies to combat malnutrition and promote sustainable food systems.

Future research should continue to explore the complex interactions between agricultural methods, environmental conditions, and the nutritional composition of green leafy vegetables to optimize their health benefits and accessibility for populations around the globe.

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Simultaneous determination of B1, B3, B6 and C vitamins in green leafy vegetables using reverse phase-high performance liquid chromatography

Comparative analysis of chlorides in plants selected from different habitats

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Abstract

The role of chloride ions (Cl^-) in plant physiology and their essential contributions across various metabolic and physiological processes, including photosynthesis, osmoregulation, enzymatic activation, and stress adaptation. Chlorides, traditionally viewed as passive elements, have now been recognized for their pivotal roles in enhancing photosynthetic efficiency, regulating osmotic balance, and enabling plants to respond adaptively to environmental stresses. This research encompasses both macroscopic investigations and molecular analyses to elucidate the multifaceted roles of chloride ions in plant biology. In addition to theoretical insights, this paper presents an empirical analysis focusing on the quantification of chloride ions in plant tissues. Using a comprehensive methodological framework, plant samples underwent a series of preparatory steps including maceration and extraction, followed by titration analysis with silver nitrate ($AgNO_3$) using potassium chromate (K_2CrO_4) as an indicator. This approach allowed for the precise measurement of chloride concentrations within the plant material, facilitating a deeper understanding of chloride distribution and its physiological implications. This work not only contributes to the broader understanding of chloride ions as critical nutrients in plant biology but also sets the stage for future research aimed at enhancing crop resilience and productivity through optimized nutrient management. The molarity of chloride ions in various plants, indicating that *Caesalpinia pulcherrima* has the highest concentration at 0.227M, followed by *Tecoma stans* at 0.1686M, *Pistia stratiotes* at 0.1266M, *Nerium oleander* at 0.122M, *Yucca gloriosa* at 0.0606M, and *Nymphaea alba* at 0.0246M.

Key words: Chloride ions, photosynthesis, osmoregulation, stress adaptation, ionic balance, *Nerium oleander* , *Pistia stratiotes* , *Yucca gloriosa, Nymphaea alba, Tecoma stans, Caesalpinia pulcherrima*

Introduction

Chloride ions, represented chemically as Cl^-, have emerged as essential micronutrients pivotal for the comprehensive physiological and metabolic functioning of plants (Marschner,2012). This transition in scientific perception—from chloride being considered a passive element to an essential nutrient—underscores a profound evolution in the understanding of plant biology (Epstein, 1972). Initially, research on chlorides concentrated on their macroscopic influence on plant growth. However, the scope of investigation has since broadened to encompass molecular and genetic studies, unveiling the nuanced roles these ions play at the cellular level (Hasegawa, Bressan, Zhu, & Bohnert, 2000). Such advancements have highlighted chloride's integral contributions to various facets of plant science, including its critical role in enhancing photosynthetic efficiency and modulating responses to environmental stresses (Munns & Tester, 2008).

Within the intricate machinery of photosynthesis, particularly the oxygen-evolving complex of photosystem II, chlorides act as more than mere participants; they are crucial facilitators (Jones & Smith, 1984). Their involvement in the photolysis of water molecules is indispensable for the efficient progression of the light-dependent reactions of photosynthesis (Yocum, 1991). This process liberates essential oxygen and protons, thereby fueling the synthesis of vital energy carriers such as ATP and NADPH. Through this mechanism, chlorides play a pivotal role in the broader energy conversion process, marking their significance in the global carbon cycle.Beyond their role in photosynthesis, chlorides are vital in regulating osmotic pressure and maintaining ionic balance within plant cells (Smith & Raven, 1979). This regulation ensures cell turgidity, allowing plants to maintain their structural integrity and upright posture even amid fluctuating environmental conditions. The ability of chlorides to modulate osmotic pressure is fundamental for plant adaptation to varying water availabilities, illustrating the adaptive capabilities facilitated by these ions (Flowers & Lauchli, 1983).

Additionally, chlorides serve as indispensable cofactors for a multitude of enzymes involved in various metabolic pathways (Marschner, 2011). By enhancing the catalytic efficiency of enzymes, chlorides influence critical biochemical reactions, spanning from nutrient assimilation to the biosynthesis of essential biomolecules. This catalytic role

underscores the foundational importance of chlorides in supporting plant growth, development, and reproductive success.

The process through which chlorides are absorbed and transported within the plant is critical for fulfilling the physiological and metabolic needs of these organisms. Root absorption of chlorides, influenced by environmental factors such as soil pH, moisture content, and the competitive presence of other ions, is a highly regulated process (White & Broadley, 2001). Specific transporters located in root cell membranes play a crucial role in ensuring that the uptake of chlorides aligns with the plant's physiological demands, thereby preventing toxic accumulations. Following absorption, the translocation of chlorides to the plant's aerial parts through the xylem involves a balanced interplay between passive diffusion and active transport mechanisms (Teakle & Tyerman, 2010). This regulated movement is essential for delivering chlorides to key sites of photosynthesis and metabolic activity. Within the leaf tissues, the strategic distribution and compartmentalization of chlorides, particularly into organelles like vacuoles, are vital for maintaining ionic balance and averting toxicity. These sophisticated strategies for managing internal chloride levels highlight the plant's capacity for intricate nutrient regulation.

Adaptation to Environmental Stresses: Chlorides are instrumental in the plant's adaptation mechanisms to environmental stressors. In drought conditions, the role of chlorides in osmotic adjustment becomes particularly pronounced. By accumulating in cell vacuoles, chlorides aid in water retention, ensuring the continuity of cellular functions despite limited water availability (Zörb, Geilfus, Mühling, & Ludwing-Müller, 2014). This adaptability to osmotic stress exemplifies the plant's dynamic regulatory mechanisms in modulating internal chloride concentrations in response to external challenges. In conditions of high soil salinity, characterized by elevated ionic toxicity and osmotic stress, plants employ various strategies to navigate the surplus of chlorides. These include the sequestration of excess chlorides within vacuoles to mitigate cytotoxic effects and the redistribution of chlorides to senescent tissues to minimize damage to growing parts (Brumos et al., 2009). Furthermore, the complex interactions between chlorides and other nutrients, such as potassium and nitrogen, accentuate the intricacies of nutrient management within plant systems (Xu et al., 2000). These interactions, which can significantly affect the uptake, assimilation, and overall utilization of nutrients,

underscore the importance of maintaining a balanced ionic environment for optimal plant health and productivity.

Despite the indispensable roles chlorides play in plant physiology, an excess of these ions can precipitate toxicity, manifesting in symptoms such as chlorosis, necrosis, and inhibited growth (Flowers & Colmer, 2008). This dichotomy underscores the necessity of delineating the delicate equilibrium between beneficial and toxic chloride concentrations for effective plant health management. Mitigation strategies encompass a range of approaches, including the judicious application of irrigation and fertilizers, the cultivation of chloride-tolerant plant varieties, and the implementation of advanced soil management practices designed to curtail the accumulation of excessive chlorides (Munns, James, & Lauchli, 2006).

Recent advances in the realm of molecular biology and genetics have significantly enriched our understanding of chloride transport and homeostasis. These breakthroughs have revealed the identity and regulatory mechanisms of specific chloride transporters, shedding light on the sophisticated systems governing chloride movement and regulation within plant tissues (Jossier et al., 2010). Complemented by methodological innovations in analytical techniques, such as ion-selective electrodes and fluorescence microscopy, researchers now possess enhanced capabilities to visualize, quantify, and comprehend the dynamic roles and regulation of chlorides in planta (Wei, Bilsborrow, & Hooley, 1999). These technological advancements have not only deepened our understanding of chloride physiology but have also paved new avenues for exploring their multifaceted roles in plant growth, development, and stress adaptation.

The knowledge accrued from extensive chloride research carries profound implications for the agricultural sector, particularly in the quest to bolster crop resilience and productivity in saline environments. Future research endeavors are poised to delve deeper into the genetic and molecular underpinnings of chloride tolerance and signaling pathways (Zhang & Blumwald, 2001). These studies aim to engineer crop varieties optimized for chloride utilization and superior adaptation to environmental stresses. Furthermore, elucidating the mechanisms underlying the interactions between chlorides and other essential nutrients presents a promising avenue for developing innovative nutrient management strategies and crop optimization techniques. Such pursuits not only

hold the potential to revolutionize agricultural practices but also underscore the pivotal role of chlorides in advancing our understanding of plant physiology, ecology, and the broader interactions within ecosystems.

Materials and Methods

Chemicals required:

Sand

Water (specifically, distilled water)

Activated charcoal

0.02N Silver Nitrate ($AgNO_3$) Solution

5% Potassium Chromate (K_2CrO_4) Solution

Standard Sodium Chloride (NaCl) Solution

Plant materials

The plant materials are collected from the garden of St. Anns College for Women, Mehdipatnam.Plant samples were prepared by first washing and drying the material. Subsequently, 1 gram of the dried plant material was crushed with neutral sand and activated charcoal to enhance the extraction process. The mixture was then macerated with 10 mL of distilled water to facilitate the extraction of soluble constituents.

For the extraction, 1 gram of the prepared plant material was diluted in 10 mL of distilled water. The solution was then filtered through Whatman filter paper to obtain a clear plant extract, suitable for further analysis.

A volume of 10 mL of the clear plant extract was titrated against the prepared 0.02N $AgNO_3$ solution, using the 5% K_2CrO_4 solution as an indicator. The end point of the titration was determined by the appearance of a faint reddish-brown color, indicating the formation of silver chromate, a signal that the titration had reached its conclusion.Standardization of $AgNO_3$ SolutionThe concentration of the $AgNO_3$ solution was standardized using the standard NaCl solution, with potassium dichromate ($K_2Cr_2O_7$) serving as the indicator. This step was critical to ensuring the accuracy of the titration

results, by confirming the molarity of the AgNO₃ solution used in the analysis of plant extracts.

Results and Discussion

Hydrophytes are plants adapted to living in or on aquatic environments. The table lists Nymphaea alba with a molarity of 0.0246, suggesting it is adapted to fresh water with low salinity, as is typical for water lilies. On the other hand, Pistia stratiotes shows a higher molarity of 0.1266, indicating it can tolerate or may prefer slightly brackish conditions.

Mesophytes are plants that require well-drained soil with moderate water, neither too wet nor too dry. Tecoma stans has a molarity of 0.1686, implying it can manage or possibly thrive in conditions with moderate salinity. Caesalpinia pulcherrima, with the highest molarity of 0.227, may have a great tolerance for saline soils, which could be advantageous in mesophytic environments that experience occasional salt accumulation.

Xerophytes like Yucca gloriosa and Nerium oleander are adapted to arid conditions with infrequent watering. Yucca gloriosa has a molarity of 0.0606, indicative of its efficiency in regulating chloride ion intake and conserving water. Nerium oleander shows a slightly higher molarity at 0.122, suggesting it might have a greater tolerance to salinity, which could be beneficial in its native environments that can sometimes be dry and saline.

.These molarity values shed light on the adaptive strategies employed by plants to navigate the challenges posed by their habitats' salinity levels. Each plant type—hydrophytes, mesophytes, and xerophytes—deploys distinct physiological mechanisms to maintain homeostasis in different environmental conditions.

Hydrophytes like Nymphaea alba and Pistia stratiotes, with their respective molarities of 0.0246 and 0.1266, illustrate the spectrum of salinity tolerance within aquatic environments. The lower molarity in Nymphaea alba suggests an adaptation to freshwater habitats, where managing influx and efflux of water and solutes is crucial to avoid cellular waterlogging. In contrast, Pistia stratiotes appears to have developed mechanisms to

tolerate higher saline conditions, possibly by compartmentalizing salts in vacuoles or synthesizing osmoprotectants to counteract the osmotic stress.

Mesophytes like Tecoma stans and Caesalpinia pulcherrima, with molarities of 0.1686 and 0.227 respectively, may indicate a remarkable versatility to withstand soil salinity fluctuations. These plants might possess root systems that can selectively absorb ions or can efficiently sequester excess salts away from critical metabolic processes. Caesalpinia pulcherrima, in particular, might express salt-tolerant genes that allow it to survive and flourish in soils that would typically be inhospitable due to high salinity.

Xerophytes such as Yucca gloriosa and Nerium oleander, with chloride ion concentrations of 0.0606 and 0.122, must often contend with both water scarcity and high soil salinity. Their physiological adaptations could include highly efficient water uptake and storage systems, salt exclusion at the root level, or the ability to shed leaves to reduce transpirational loss. Their particular chloride ion concentrations reflect a fine-tuned balance between the uptake of necessary nutrients and the prevention of salt-induced damage.

While hydrophytes like Nymphaea alba and Pistia stratiotes display a range of tolerance to aquatic salinity levels, mesophytes like Tecoma stans and Caesalpinia pulcherrima show adaptations to soil salinity variations. Xerophytes such as Yucca gloriosa and Nerium oleander are adapted to conserving water and tolerating the saline conditions often found in arid and semi-arid ecosystems.
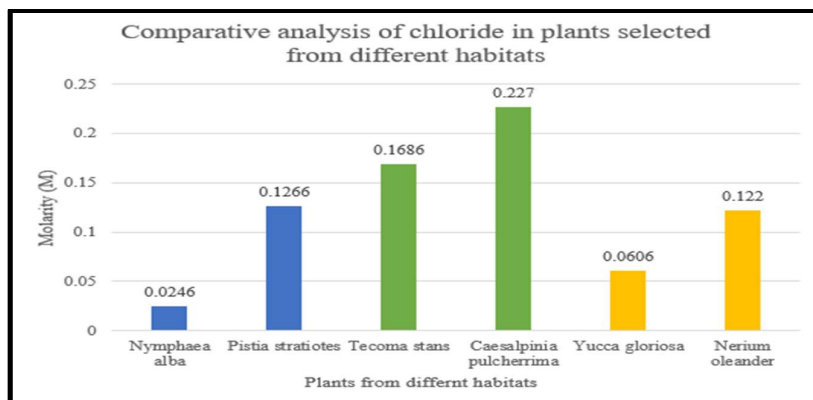
Graph. Comparative analysis of chlorides in plants selected from different habitats

The graph titled "Comparative Analysis of Chloride in Plants Selected from Different Habitats" effectively illustrates the variance in chloride concentration among plants adapted to diverse ecological niches. It highlights the chloride molarity in hydrophytes, mesophytes, and xerophytes, differentiated by color coding for clarity. Hydrophytes, marked in blue, show Nymphaea alba with the lowest molarity of 0.0246M, suggesting an adaptation to low-salinity water environments. Pistia stratiotes exhibits a higher tolerance to salinity with a molarity of 0.1266M. The mesophytes, shown in green, reveal Tecoma stans and Caesalpinia pulcherrima with molarities of 0.1686M and 0.227M, respectively, indicating a capacity to endure or possibly prefer soil with moderate to high salinity levels. The xerophytes, represented in yellow, include Yucca gloriosa with a molarity of 0.0606M, which may suggest mechanisms for salinity regulation in arid conditions, while Nerium oleander displays a slightly higher molarity of 0.122M, possibly indicating a greater resilience to saline soils common in dry habitats. This visual representation underscores the relationship between plant types and their environmental salinity adaptation strategies.

The findings from our comprehensive analysis underscore the vital roles of chloride ions in plant physiology, echoing and extending existing research that highlights the multifaceted functions of chlorides in photosynthesis, osmoregulation, enzymatic activation, and adaptation to environmental stresses. The empirical segment of our study, focused on quantifying chloride ions in plant tissues through titration with silver nitrate and using potassium chromate as an indicator, has provided precise measurements of chloride concentrations. This not only facilitates a deeper understanding of chloride distribution within plants but also underscores the importance of chloride ions in maintaining plant health and optimizing physiological processes.

Our study's results on photosynthetic efficiency bolster the argument that chlorides are more than passive elements in the photosynthesis process. They are, in fact, crucial facilitators within the oxygen-evolving complex of photosystem II, corroborating findings from previous studies (Jones, 1984; Smith & Raven, 1979). This role in the photolysis of water molecules is indispensable for the efficient progression of the light-dependent reactions of photosynthesis, echoing the critical nature of chlorides in the broader energy conversion process and their significance in the global carbon cycle.

Regarding osmoregulation and ionic balance, our findings align with the consensus that chlorides are fundamental in regulating osmotic pressure within plant cells (Hasegawa et al., 2000). This regulation is crucial for plant adaptation to varying water availabilities, illustrating the adaptive capabilities facilitated by chlorides. The enzymatic activation role of chlorides, as revealed through our analysis, emphasizes their indispensability as cofactors, thereby impacting crucial biochemical pathways essential for plant growth and development.

The uptake and transport mechanisms for chlorides, as elucidated in our study, highlight the sophisticated strategies plants employ to manage internal chloride levels. This regulated movement is essential for delivering chlorides to key sites of photosynthesis and metabolic activity, further supported by previous research indicating the importance of specific transporters in root cell membranes (White & Broadley, 2001).

Our investigation into plants' adaptation mechanisms to environmental stressors, especially under drought conditions and high soil salinity, sheds light on the dynamic regulatory mechanisms at play. These findings dovetail with studies demonstrating the pivotal role of chlorides in osmotic adjustment and stress adaptation (Munns & Tester, 2008). The intricate interplay between chlorides and other nutrients, highlighted in our analysis, underscores the complexity of nutrient management within plant systems, an area ripe for further exploration.

However, the dual nature of chlorides as both essential and potentially toxic necessitates a delicate balance for optimal plant health, resonating with the broader literature on plant nutrient management (Marschner, 2012). Our study's emphasis on mitigation strategies for chloride toxicity, including the cultivation of chloride-tolerant varieties and advanced soil management practices, offers practical avenues for addressing the challenges posed by excessive chloride levels.

Conclusion

The comprehensive analysis presented in this research paper significantly advances our understanding of the essential roles played by chloride ions in plant physiology, highlighting their critical contributions to photosynthesis, osmoregulation, enzymatic

activation, and adaptation to environmental stresses. Through a meticulous empirical approach, we have quantified chloride concentrations in plant tissues, shedding light on the intricate distribution and physiological significance of these ions. The results affirm the indispensability of chlorides in facilitating the efficient operation of photosynthetic processes, regulating osmotic pressure for plant turgidity, acting as cofactors in enzymatic reactions, and aiding plants in their adaptation to environmental challenges.

Our findings underscore the delicate equilibrium that plants must maintain in their internal chloride levels to sustain health and development. While essential for numerous physiological processes, an imbalance, particularly an excess of chlorides, can lead to toxicity, highlighting the importance of nuanced nutrient management strategies. This dual nature of chloride ions—as both vital nutrients and potential toxins—emphasizes the need for ongoing research to optimize chloride management in agricultural practices.

This study contributes to the growing corpus of knowledge on plant nutrient management, suggesting avenues for the development of chloride-tolerant crop varieties and innovative agricultural practices to enhance crop resilience and productivity. The implications of our research extend beyond the academic realm, offering practical insights for the agricultural sector in managing chloride levels, thus ensuring plant health and optimizing yield in environments challenged by salinity and other stressors.

The pivotal roles of chloride ions in plant biology are undeniable, with their influence permeating various critical physiological and metabolic processes. As we deepen our understanding of these roles and develop innovative strategies to manage chloride levels effectively, we move closer to achieving resilient and productive agricultural systems capable of supporting the growing global population.

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MOLECULAR IDENTIFICATION AND ANTIMICROBIAL ACTIVITY OF PROBIOTIC BACTERIA ISOLATED FROM ICE APPLE

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ABSTRACT : Probiotic bacteria, such as lactic acid bacteria are gram-positive organisms that can withstand various environments throughout the production and storage of the goods comprising them. Probiotic bacteria can help the host's health, when consumed in the right quantities. Isolating and identifying Ice apple bacteria strains with probiotic potential is the goal of this research. De-man Rogosa & Sharpe agar (MRS), MRS broth for isolating probiotics by streaking method, and nutritional agar were all thoroughly sterilized before use in the study. Ten different bacterial isolates were experimented with for their biochemical and cultural characteristics. Four isolates displayed antibacterial behavior with human pathogens (*Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas fluorescens*, *Bacillus subtilis* and *Staphylococcus aureus*). At the same time, six showed no zone of inhibition after being tested against a range of antibiotics. The isolates were found to be members of the *Lactobacillus leichmannii* species after undergoing a molecular identification study (16sRNA sequencing). These probiotic activity findings prove that bacteria isolated from ice apple samples possess intriguing capabilities exhibit potential as probiotics and can enhance the storage period of fresh fruit and vegetables.

Key words : Probiotics, *Lactobacillus*, ice apple, molecular identification, antibacterial activity.

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INTRODUCTION

Elie Metchnikoff first proposed the term "probiotic" in his observation that fermented milk consumption could counteract the putrefactive effects of gut bacteria. People have been adding beneficial bacteria called probiotics to their diets for twenty years. The rising popularity of this functional food is a direct result of people's growing interest in eating healthier (Peera and James, 2012). "A live microbial dietary supplementation which positively impacts the host animal through enhancing its microbial balance" (Axelsson, 1998). Probiotic microorganisms have been found to synthesize bacteriocins, reuterin and organic acids (including lactic acid and acetic acid), all of which have antimicrobial properties. The pH of an area can be lowered, and the presence of organic acids can stunt the proliferation of bacteria. Diarrhea, dysentery, typhoid, etc., can all be helped by taking probiotics (Tambekar *et al*, 2010). When discussing the efficacy and biological activity of probiotics, prebiotics, or a mix of the two (synbiotics), it is essential to emphasize that they are foods, not pharmaceuticals. There are a wide variety of probiotic dietary supplements and foods on the market today and the probiotic bacteria present in each one must endure a unique set of stresses during production and preservation, including extremes in heat and cold, changes in water activity (aw), acidity, oxygen levels, and the existence of other microbes or potentially toxic chemicals. Certainly, the bacterial strains need to be able to be stored and still be alive after preservation before they can be employed. Stocking typically involves either freezing or drying. Not only must the strains endure each stressful environment, but they need also to be alive and able to grow (Hoque *et al*, 2010). Knowing how the method and storage may influence the strains is crucial. In addition, their benefits are often more prophylactic than therapeutic, meaning they serve to avoid illness rather than treat it (Hoque *et al*, 2010; Nazneen and Sultana, 2024).

The scientific literature referred to Lactic acid bacteria as probiotics (Ram *et al*, 2013). Lactic acid bacteria (LAB) are Gram-positive, non-spore-forming cocci or rod-shaped bacteria that consume carbohydrates

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Ethical approval : The authors confirm that there are no ethical issues in the publication of the manuscript.

Human and animal rights : No animals/humans were used for studies that are the basis of this research.

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Isolation and Identification of probiotic bacteria from natural Neera to extend the shelf life of fresh fruits and vegetables

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Abstract

Packaging and processing techniques in the food sector can adversely impact both consumer health and the environment. Consequently, there's a growing demand for minimally processed foods that retain their nutritional and sensory qualities while ensuring extended shelf life. Edible coatings have emerged as a promising solution, offering improved quality, safety, and functionality for perishable items like fruits and vegetables. These coatings regulate water diffusion, gas permeability, and oxidation, and can be applied through dipping, spraying, or coating methods. A recent study focused on isolating probiotic bacteria from Neera samples collected near Choutuppal in Nalgonda, Telangana. Ten bacterial strains were cultivated from these samples on MRS agar and subsequently sub-cultured to obtain pure cultures. Morphological analysis confirmed the purity of each culture. The isolates were then assessed for antimicrobial activity against spoilage-causing microorganisms in fruits and vegetables. Biochemical tests, including catalase, methyl red, oxidase, starch hydrolysis, citrate utilization, and Voges-Proskauer tests, were conducted to characterize the isolates. Among the ten strains, isolate 3 demonstrated the most promising characteristics, including strong antibacterial activity. Molecular identification using universal 16S rRNA primers identified this isolate as Levilactobacillus brevis. Phylogenetic analysis using Mega-4 bioinformatics software further confirmed its identity. This strain exhibited excellent performance in bile salt tolerance tests and demonstrated other probiotic activities, highlighting its potential as a functional food ingredient. The findings underscore the significance of probiotics in enhancing food quality and safety, offering a natural solution to meet consumer preferences for healthier and longer-lasting food options.

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Introduction

Fruits and vegetables are an important part of a healthy diet due to their low-calorie content (Charlton *et al.*, 2014) and several health benefits (Berger *et al.*, 2010). Consuming a diet rich in fruits and vegetables has been shown to lower the risk of several diseases, including cardiovascular disease, colon cancer, obesity, and diabetes (More *et al.*, 2020). They have become increasingly popular in recent years, and their richness of nutrients makes them necessary for everyday use (Leneveu-Jenvrin *et al.*, 2020). Producing minimally processed fruits and vegetables has helped meet the rising demand for fresh produce (both whole and cut) in many developed countries over the past decade. This is because these foods are both nutritious and easy to prepare. Fruits and vegetables that can be stored for longer without losing their quality are one way in which minimal processing techniques are replacing more conventional ones (De Corato *et al.*, 2020; Hasan *et al.*, 2020). Food quality declines during preservation, a major issue for food manufacturers and a significant contributor to food waste. Recently, novel and effective food handling methods have been invented to lead to the extension of food safeguarding, shelf-life extension, and, thus, food waste decrease (Stan *et al.*, 2019; Stan, 2020; Verma *et al.*, 2021; Chitrakar *et al.*, 2021; Nezami, 2020). But not all of these cutting-edge technologies are viable commercial solutions because they influence customer behavior (Rabadán *et al.*, 2021; Stefanoiu *et al.*, 2018). Edible packaging, coatings, and films are novel solutions to this issue because they protect perishable goods, delaying spoilage from microorganisms and preventing loss of moisture and gas (Dehghani *et al.*, 2018).

Research into edible packaging systems is increasing annually as more people seek less conventional and more nutritious foods. Senses of smell, taste, and sight can be preserved using edible films and coatings as the principal packaging material for goods with edible ingredients. The ripening of produce coated with edible films is slowed, and its shelf life is extended (Hassan *et al.*, 2018; Ulusoy *et al.*, 2018). Wax was applied to oranges in China in the 12th and 13th centuries to create an edible coating. Edible coatings produced from boiling soybeans were developed in Japan in the 15th century (Tural *et al.*, 2017) and were used to enhance the visual appeal of various foods. The edible packaging industry has proliferated in the past few years, with a projected valuation of $1097 million by 2023 (Mamtani *et al.*, 2021). Edible packaging has two separate applications in the food sector. Edible coatings can be sprayed directly onto the food item or onto a prefabricated film that is then coiled around the food item (Suhag *et al.*, 2020).

The food sector needs help with customer acceptability regarding novel manufacturing methods, such as edible coatings and films (Vital *et al.*, 2018), even though these can assist in extending the shelf life of numerous food items. Consumer acceptability is vital to the production of effective food products. Hence insight into how consumers create and interpret opinions about novel technology and goods is essential for food chain invention (Stan *et al.*, 2019; Siegrist *et al.*, 2021). Several studies have been conducted to determine whether or not consumers will embrace novel processing technologies and techniques, such as nanotechnology (Peters *et al.*, 2016), radio frequency (Stefanoiu *et al.*, 2018), food irradiation (MacRitchie *et al.*, 2014), and edible coatings and films (Wan *et al.*, 2007). This investigation examines the current state of knowledge regarding the use of edible formulations on a variety of less processed fruits and vegetables, with a particular emphasis on the scientific aspects of this practice, involving coating ingredients and composition, implementation techniques, and the impact on food shelf life and quality, which involves nutritional quality.

Probiotics are live bacteria that help humans stay healthy. Maintaining viability and metabolic activity is essential from when food is harvested until the consumer consumes it. Although protecting against these microbes is crucial, the question of when and where to release them still needs to be answered. There is no issue with release when employing edible

films or food coatings because they are both ingested with the food. However, these coatings help extend the storage life of perishable commodities like fresh produce. Beneficial microbes, or probiotics, aid humans when consumed in adequate amounts. Protecting against harmful germs, boosting mucus formation, and improving gastrointestinal mucosa proliferation are all functions these microorganisms perform well. Additionally, they contain immunogenic qualities that lessen the side consequences of diarrhea, avoid intestinal inflammation, lower blood cholesterol levels, prevent allergies, and regulate genital and urinary tract diseases (E Silva *et al.*, 2014). One of the most efficient ways to obtain probiotics is by incorporating them into your food, including cornflakes (Dadgar *et al.*, 2014), pomegranate juice (Khanbagi Dogahe *et al.*, 2015), dough (Javanmard *et al.*, 2013), cheese (Tavakoli *et al.*, 2016), yogurt (Massoud *et al.*, 2015; Beheshtipour H *et al.*, 2012), processed milk (Beheshtipour *et al.*, 2013), and grape drink (Malganji *et al.*, 2016). Helpful substances and bioactive substances are produced by probiotic varieties during their residency, including peptides with opiate and antithrombotic effects, attached linolenic acid, and propionic acid (Massoud *et al.*, 2015; Gholami *et al.*, 2014; Farhadi *et al.*, 2013).

Using these beneficial microbes has been reported to decrease oxidative stresses and inflammatory mediators (Mohammadi *et al.*, 2015; Mohammadi *et al.*, 2015), as well as remove poisons and heavy metals (Massoud *et al.*, 2020; Siahmoshteh *et al.*, 2016). As stated by Hosseini *et al.* (2013) and Soheili *et al.* (2011), prebiotics are used to promote the development of probiotics. More research into the human gut microbiome can lead to identifying hitherto unrecognized prebiotics and probiotics (Gómez *et al.*, 2016). Probiotics' survival and metabolic activity must be preserved through food manufacturing, after ingestion, and within the gastrointestinal system (Nguyen *et al.*, 2016). For example, lactic acid bacteria have been shown to increase the nutritional value of foods by contending with pathogens for nutrients (such as vitamins,

minerals, trace elements, and peptides) and by creating organic acids and bacteriophages (antimicrobial peptides) to combat spoilage during storage. Thus, using probiotics might lengthen the period that vegetables and fruits can be stored, avoiding being linked to their antagonistic effects (Alegre *et al.*, 2011). Protecting fruits and vegetables with edible coverings has become a common practice recently. By limiting postharvest moisture loss, gas exchange, respiration, and oxidative processes, edible coating with semi-permeable films might extend the storage life of fruit (Khodaei *et al.*, 2019; Petriccione *et al.*, 2015). Films and coatings for edibles can be fabricated from a wide range of biocompatible materials, including lipids, polysaccharides, proteins, and their respective combinations (Pereira *et al.*, 2016). The food packaging business and the network of edible polymer films can both benefit from the incorporation of probiotics. An alternate strategy for managing dangerous microbes and bolstering food safety is provided by incorporating probiotics and other active chemicals into the structure of biopolymers. Research on both probiotics and food packaging has increased over the past two decades (Espitia *et al.*, 2016), yet there has been relatively little research on the use of probiotics in food packaging. It was first suggested in 2007 (Tapia *et al.*, 2007) that probiotics may be used in consumable films. Therefore, there is continuing investment in the study and production of probiotics films and coatings for proactive packaging. These coatings and films could serve as viable replacements for transporting probiotics. Active or bioactive packing, like probiotic material for packaging, can improve food stability and even positively affect the health of the customer. This research aimed to determine which strains of lactic acid bacteria could be isolated from Neera to improve food safety and shelf life without sacrificing nutritional value.

Materials and methods

Study Location and Sample Collection

A total of 3 samples were collected from the local areas of Choutuppal, Nalgonda, and Telangana, and processed for isolating new bacterial strains.

Media

HiMedia Laboratories Pvt. Ltd., Mumbai, India, was contacted for the acquisition of *Lactobacillus* (MRS) agar, broth, and an antibiotic susceptibility disc. The pathogens were obtained from the Microbial Type Culture Collection and Gene Bank (MTCC), Chandigarh, India, and their accession numbers are as follows: *Bacillus subtilis MTCC 10403, Escherichia coli MTCC 4430, Pseudomonas aeruginosa MTCC 424, Micrococcus luteus MTCC 1809, and Salmonella typhimurium MTCC 98.*

Bacterial Isolation from Neera

The microbial population in the obtained neera samples was enriched by inoculating them into enrichment media (MRS broth media). After letting the batters ferment overnight, they were diluted serially (phosphate saline 0.1 M, pH 7.2) and poured onto a plate of MRS agar that had hardened. 24-48 hours of anaerobic incubation were conducted at 37 degrees Celsius. Pure cultures were streaked onto an MRS agar plate after being selected from colonies with distinct morphological features. Isolated settlements were sub-cultured in MRS broth and kept at four °C until storage. The isolated strains were processed into an extract (CE) and supernatant (CS) according to the protocol described by Jo *et al.* (2021). Remote pure cultures were then subcultured onto slants for additional study using the spread plate method. The morphological, biochemical, and molecular analyses relied on these pure cultures.

Antibacterial activity

Preparation of nutrient agar plates followed by the spreading of lab cultures of pathogenic bacteria, including *Pseudomonas fluorescens* (MTCC 9768), *Escherichia coli* (MTCC 424), *Staphylococcus aureus* (MTCC 96), *Klebsiella pneumoniae* (MTCC 272), and *Bacillus subtillis* (MTCC 3053). The paper-dip approach is then used to place the triggered samples and wait 24 hours. After 24 hours of incubation, a distinct zone of bacterial inhibition was visible surrounding the selection and quantified. Anti-bacterial activity-displaying models are used in further research (Mohamed *et al.*, 2020).

Biochemical identification of the bacterial isolate PKN 3

Gram staining, indole test, methyl red test, Voges-Proskauer test, citrate utilization, catalase test, and glucose fermentation test were used to identify bacterial isolate PKN 3 morphologically. Bergey's Manual of Systematic Bacteriology (Sneath *et al.*, 1986) was used for all tests.

Evaluation of probiotic attributes in vitro
Acid and bile salt

With a few tweaks, the acid and bile salt tolerance experiments were conducted using the same methods as Pan *et al.* (2009) stated. The MRS broth (pH two and (0.3 and 1%) ox gall salt) was infected with 100 L of the isolates and incubated at 37°C. The samples were counted after 0, 2, and 4 hours of incubation.

Molecular identification of PKN 3 based on 16S rRNA gene sequence

The PKN 3 isolate was sent to MACROGEN (Seoul, Korea) to be sequenced with universal 16S rRNA primers to determine its molecular identity.

Mega-4 was used for the phylogenetic analysis in this study. The sequence of 16S rRNA has been uploaded to NCBI.

Results and discussion
Morphological studies

Gramme staining was used to determine the morphological identity of the isolates. Isolates were discovered to be a creamy white tint and to have an uneven, spherical shape. The sizes of the isolates varied widely. Flat to undulating in height, completely opaque around the edges.

Antibacterial activity

MTCC 3053 *Bacillus subtilis*, MTCC 96 *Staphylococcus aureus*, MTCC 274 *Klebsiella pneumoniae*, MTCC 424 *Escherichia coli*, and MTCC 9768 *Pseudomonas fluorescens* were used to assess the antibacterial properties of neera isolates. Plant extracts made with methanol performed significantly better than those from other solvents (Figs 2–6).

Table 1. Morphological studies of the pure isolates.

Isolate no	Color	Shape	Size	Elevation	Margin	Opaque
Isolate 1	Cream white	Irregular	large	Raised	Filiform	Non-Transparent
Isolate 2	Cream white	Circular	Large	Raised	Entire	Non-Transparent
Isolate 3	Cream white	Irregular	Medium	Raised	Undulate	Non-Transparent
Isolate 4	Cream white	Circular	Large	Raised	Entire	Non-Transparent
Isolate 5	Cream white	Irregular	Medium	Flat	Undulate	Transparent
Isolate 6	Cream white	Irregular	Medium	Flat	Undulate	Non-Transparent
Isolate 7	Cream white	Circular	Small	Slightly raised	Entire	Non-Transparent
Isolate 8	Cream white	circular	Medium	Flat	Entire	Transparent
Isolate 9	Cream white	irregular	Large	Flat	Undulate	Non-Transparent
Isolate 10	Cream white	irregular	small	flat	entire	Non-Transparent

Table 2. Zone of inhibition of isolates against pathogens.

Isolate no	*Bacillus*	*staphylococcus*	*Klebsiella*	*E. coli*	*Pseudomonas*
Isolate 1	0	0.7cm	0.8cm	0	1.2cm
Isolate 2	0	0	0.5cm	1.0cm	1.1cm
Isolate 3	1.0cm	0.7cm	0.6cm	0.6cm	1.7cm
Isolate 4	0	0	0	0.4cm	1.1cm
Isolate 5	0	0	0.7cm	0	1.0cm
Isolate 6	1.0cm	0.4cm	0	0	1.5cm
Isolate 7	0.7cm	0	0	0	1.5cm
Isolate 8	1.2cm	0	0	0.6cm	1.0cm
Isolate 9	1.0cm	0	0	0.6cm	1.0cm
Isolate 10	0.8cm	0	0	0	1.3cm
Amp antibiotic	1.9cm	1.0cm	1.0cm	1.3cm	2.0cm

Ten bacterial isolates were used to assess the antibacterial activity, and the results are summarised in Table 2 Isolate 3 (1.7cm) had the best antibacterial activity versus Pseudomonas, followed by isolate 6 (1.5cm) and isolate 10 (no action). Isolate 1 had the highest antibacterial activity against *Klebsiella pneumonia* MTCC 272 at 0.8cm, while isolates 6–10 had none. Antibacterial activity against *Bacillus subtilis* MTCC 3053 was harmful to Isolate 1, 2, 4, and 5, positive for Isolate 8, and highest for Ampicillin (1.9cm). Ampicillin showed similar significant action (0.80 cm) against *Staphylococcus aureus* MTCC 96 (1.0 cm), isolate 3 (0.7 cm), and no activity against isolates 2, 4, 5, 7, 8, 9, and 10.

Table 3. Morphological characteristics of isolates.

S. No.	Morphological characteristics	Observations
1	Surface	Smooth, Creamy
2	Opacity	Translucent
3	Color	Off white
4	Motility	Non motile
5	Gram staining	Positive
6	Cell shape	Rods

Table 4. Biochemical tests against bacterial isolates.

S. No.	Tests performed	Observations
1	Indole	Negative
2	Methyl red	Positive
3	Vogues Proskauer	Negative
4	Citrate	Negative
5	Catalase	Negative
6	Oxidase	Negative
7	Starch hydrolysis	Positive

All of the isolates tested positive for antibacterial activity against *Pseudomonas fluorescens* MTCC 9768, with Ampicillin producing the best results (2.0cm), Isolate three coming in second (1.7cm), Isolates 7 and 8 tied for third (1.5cm), and so on.

Fig. 1. Neera sample collected from the local area.
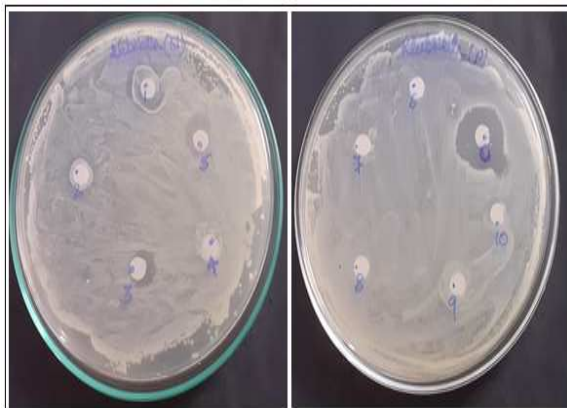
Fig. 2. Neera sample antibacterial activity against *Klebsiella*.

Gram staining techniques were used to conduct morphological analyses of the isolates (Table 3).

Fig. 3. Neera sample antibacterial activity against *pseudomonas*.

The research discovered that the isolates' surfaces were creamy and smooth, with a translucent opacity. The isolates were non-motile and appeared to be an off-white tint. Isolates were gram-positive and rod-shaped when tested.

Fig. 4. Neera sample antibacterial activity against *E coli*.
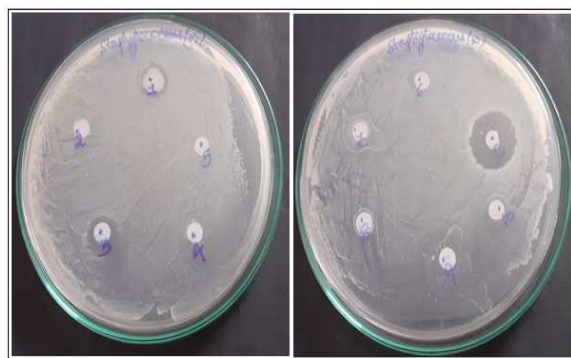
Fig. 5. Neera sample antibacterial activity against *staphylococcus*.

Biochemical Characterization

The indole assay evaluates the microbe's ability to metabolize the amino acid tryptophan into indole (Table 4). The appearance of a red hue in the media indicates the existence of indole.
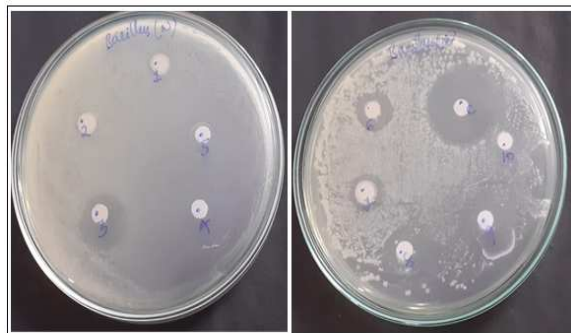
Fig. 6. Neera sample antibacterial activity against *Bacillus*.

The sample fails because the top layer of isolates does not become the expected cherry red in the Indole test. We added a few drops of a methyl red solution to MR media after incubating bacterial isolates in the medium at 35 degrees Celsius for 48 hours to show the presence of mixed acid fermentation metabolites in glucose media. The isolates above tested positive for the MR test because they turned red when exposed to methyl red. The VP test involved inoculating the VP medium with bacterial isolates, incubating the mixture at 35 degrees Celsius for two days, and adding alpha-naphthol and potassium hydroxide.

Levilactobacillus brevis strain PKN 3 16S ribosomal RNA gene, partial sequence
GenBank: OQ852041.1
FASTA Graphics

Go to: ▼

```
LOCUS       OQ852041              1155 bp    DNA     linear   BCT 26-APR-2023
DEFINITION  Levilactobacillus brevis strain PKN 3 16S ribosomal RNA gene,
            partial sequence.
ACCESSION   OQ852041
VERSION     OQ852041.1
KEYWORDS    .
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  ORGANISM  Levilactobacillus brevis
            Bacteria; Bacillota; Bacilli; Lactobacillales; Lactobacillaceae;
            Levilactobacillus.
REFERENCE   1  (bases 1 to 1153)
  AUTHORS   Phani Kumari,V. and Kavita,W.
  TITLE     Probiotic bacteria from NEERA
  JOURNAL   Unpublished
REFERENCE   2  (bases 1 to 1153)
  AUTHORS   Phani Kumari,V. and Kavita,W.
  TITLE     Direct Submission
  JOURNAL   Submitted (21-APR-2023) Department of Biochemistry, OSMANIA
            UNIVERSITY, TARNAKA, HYDERABAD, TELANGANA 500007, India
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                     /mol_type="genomic DNA"
                     /strain="PKN 3"
                     /db_xref="taxon:1580"
     rRNA            <1..>1155
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>OQ852041.1 Levilactobacillus brevis strain PKN 3 16S ribosomal RNA gene, partial sequence
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CTAATCTCTTAAAGCCGTTCTCAGTTCGGATTGTAGGCTGCAACTCGCCTACATGAAGTTGGAATCGCTA
GTAATCGCGGATCAGCATGCCGCGGTGAATACG

Fig. 7. Molecular identification of isolates 3.

The conversion of glucose to acetone produces a pleasant red color change. When V-P reagents I; and II were added to the test tubes, the isolates did not change color. Isolates failed the VP test because they did not become red when subjected to the V-P test.

Bacteria can convert citrate to oxaloacetate, which is then converted to pyruvate and carbon dioxide. The change in color from green to bright blue after 48 hours of incubation indicates that the media's pH has increased (to greater than 7.6).
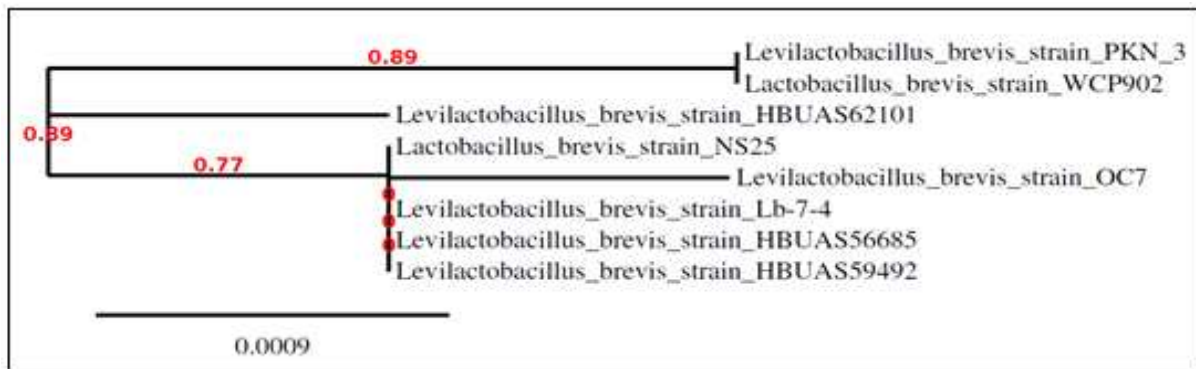
Fig. 8. Phylogenetic tree of isolates 3.

All of the isolates have been observed to have the same medium color. All ten isolated specimens tested negative.

There would be no growth of bacteria if they could not use citrate. The oxidase assay showed similar outcomes. All of these isolates also passed the starch hydrolysis and Casein hydrolysis tests.

Molecular identification of PKN 3 based on 16S rRNA gene sequence

The amplified 16S rRNA sequences of isolate 3 Neera were subjected to evolutionary analyses using the MACROGEN (Seoul, Korea) for sequencing using universal 16S rRNA primers that were > 95% like *Levilactobacillus brevis* strain, thus validating the homology sequences of the isolates (Fig. 7).
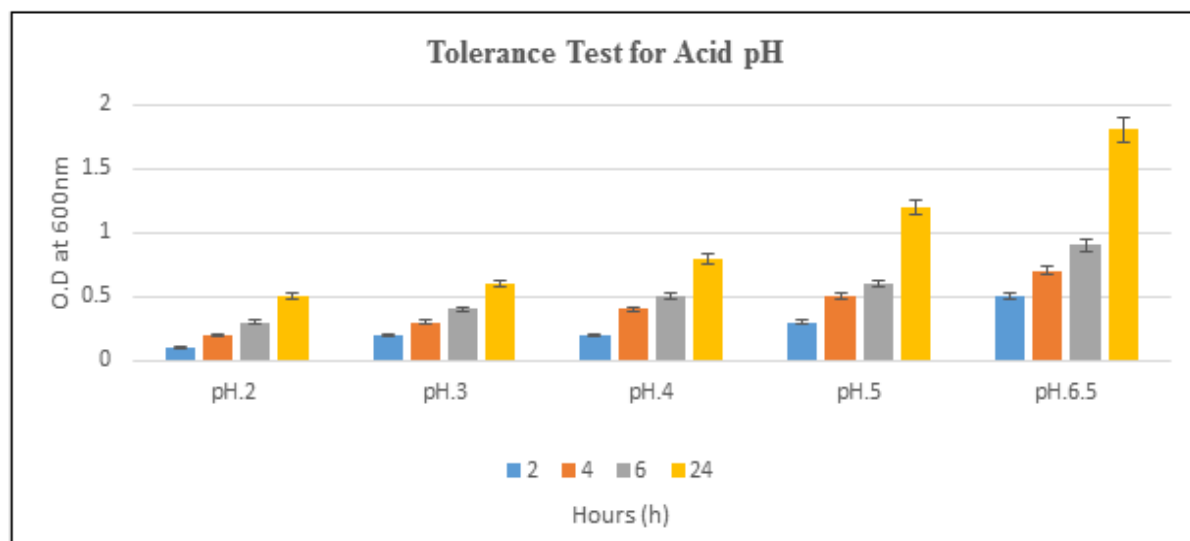
Fig. 9. Tolerance test for acid pH against the isolates of the Neera sample.

Phylogenetic tree construction

Mega-4 was used for the phylogenetic analysis in this study. The sequence of 16S rRNA has been uploaded to NCBI. Three phylogenetic groups representing the genus *Levilactobacillus brevis* were found among the lactic acid bacteria isolated from Neera sample leaves. Strains PKN_3, WCP902, HBUAS62101, NS25, OC7, LB-7-4, HBUAS56685, and HBUAS59492 were shown to belong to the *Levilactobacillus brevis* phylogenetic cluster (Fig. 8).

Tolerance Test for Acid pH

In this study, the selected isolate PKN 3 was used for acid tolerance tests with various pH conditions including pH 2, pH 3, pH 4, pH 5, and pH 6.5. optimum growth was observed at pH 6.5 at 24 hours incubation period (Fig. 9).

Test of Bile Salt Tolerance

For gauging acid and bile tolerance, the survival rate of all isolates examined from pH 2 to 6.5 was

determined under bile circumstances (0.05, 0.1, and 0.3%). Survival of the isolate from pH 2 to 6.5 and tolerance of 0.05 and 0.3% acid bile are shown in Figure 10. Isolate strains had the most effective 24-hour survival rate of 1.8 in 0.05 and 0.3% acid bile, respectively. Specifically, PKN 3 was employed for acid tolerance testing with varying bile salt levels (0.05%, 0.1%, and 0.3%) in this investigation (Fig. 10).
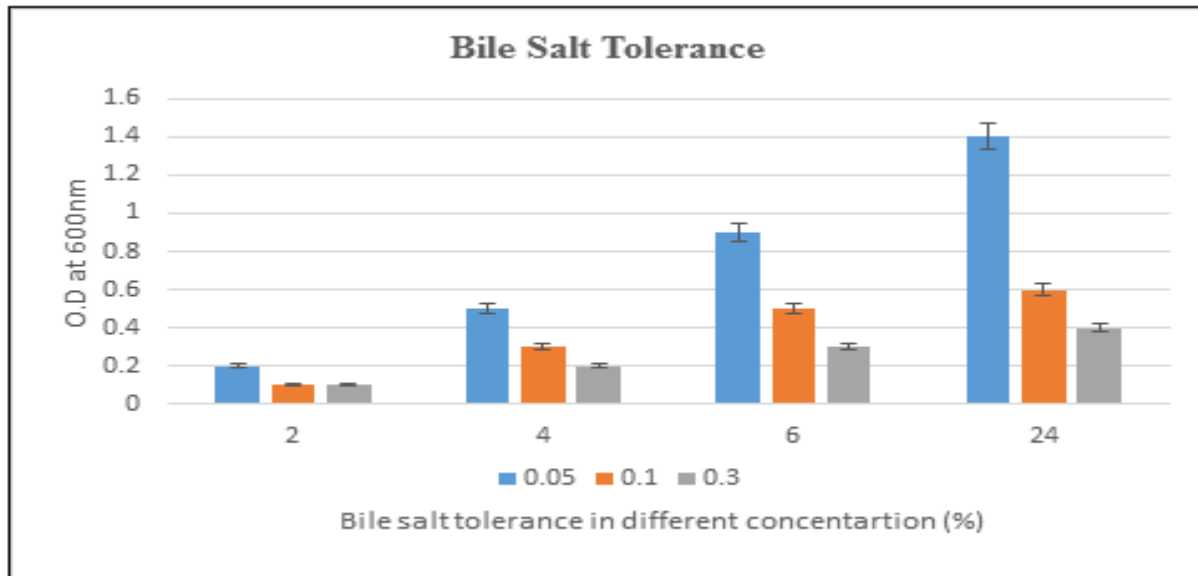
Fig. 10. Bile salt tolerance test for the isolates of Neera sample.

Conclusion

Microorganisms known as foodborne pathogens are naturally present in fresh fruits and vegetables and are typically linked to foodborne disease outbreaks. Despite the widespread use of chemical methods for controlling these infections, the food industry has turned to biological management to maintain safety and reduce pollution in response to consumer desire for natural, "chemical-free," and "more mature" fresh products. There is substantial evidence that Neera isolates protective cultures that can suppress the growth of diseases without altering the flavor of foods, making them a valuable tool for biocontrol. This research aims to identify and characterize the potential probiotics isolated from the Neera sample and tested in a spray formulation designed to extend the freshness of produce. Isolate 3 was determined to be a strain of *Levilactobacillus brevis* depending on its morphological, biochemical, and molecular characteristics. The strain performed admirably in tests measuring acid-bile, pH tolerance, and antibacterial activity—all required for classification as probiotics. These bacterial strains may find applications in many commercial and industrial contexts. Therefore, the isolates should be evaluated as possible probiotics to maintain the nutritional composition and extend the shelf life of the fruits and vegetables. However, more research is needed to do so.

Declaration

The authors declare no conflict of interest to report regarding this research work.

Ethical approval

The authors confirm that there are no ethical issues in the publication of the manuscript.

Human and animal rights

No animals/humans were used for studies that are the basis of this research

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Research Article

Viscous Dissipation and Chemical Reaction on Radiate MHD Casson Nanofluid Past a Stretching Surface with a Slip Effect

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ARTICLE INFO

ABSTRACT

This article explains the MHD Casson nanofluid flow in the presence of chemical reaction coefficient past a linear stretching surface along with the slip condition. Mainly, the analysis of heat and mass transfer in the presence of Brownian motion and the thermophoretic diffusion effect is performed. Mathematical modeling for the law of conservation of mass, momentum, hear and concentration of nanoparticles is executed. Governing nonlinear partial differential equations are transformed into the dimensionless nonlinear ordinary differential equations by using appropriate transformations. To achieve numerical solution for the considered model, shooting technique and Adams-Moulton method of fourth order are used to obtain the numerical results via the computational program language FORTRAN. Comparison between the obtained results and previous works are well in agreement was observed. For the velocity, temperature, and concentration profiles, numerical computations are conducted. The effects slip parameter, velocity ratio parameter, Casson parameter, Casson parameter taken the problem. Numerical values of the local skin-friction, Nusselt number and nanoparticle Sherwood number are computed and analyzed. It is noted that the skin-friction coefficient decreases for the larger values of velocity ratio parameter, slip parameter, and increases with an increasing value of Casson parameter. It is also found that enhancing the chemical reaction parameter leads to decrease in concentration profile. In addition, physical quantities of absorption like skin friction, local Nusselt and Sherwood numbers are also shown graphically.

1. Introduction

In the last few years, the non-Newtonian fluids attracted the attention of the mathematicians, physicist, engineers, etc., due to their demanding applications of domestic and industrial usage. In our daily life such applications are all around us, from a morning coffee to an evening bath. Such applications include toothpaste, paints, gels, lubrication oils, polymers, etc., The Navier Stokes equations due to their composite structure, cannot effectively describe the flow of non-Newtonian fluids. In the non-Newtonian fluids, the constitutive equations exist much more complex than the Navier Stokes equations. There is no one constitutive equation that can be used to study all non-Newtonian fluids, explaining the complex behavior of fluids. Some relevant studies

about non-Newtonian fluids can be seen from the list [1,2].

Casson fluid is discussed under the class of non-Newtonian fluids. Shortcomings of the Bingham fluid model is countered by this model as it explains the nonlinear behavior seen once the yield stress is achieved. The Casson fluid model successfully explains the physical behavior of many fluids used in science and industry. For instance, in chocolate manufacturing industry, the quality of chocolate products depend on the viscosity of the chocolate. Chocolate shows a shear thinning behavior which is explained best by the Casson fluid model [3]. Narender et al. [4] studied the impact of the radiation effects in the presence of heat generation/absorption and magnetic field on the magnetohydrodynamics (MHD) stagnation point flow over a radially stretching sheet using a Casson nanofluid. The method employed by the authors is the shooting method with Adams – Moulton method. Narender et al. [5] explored the impacts of external magnetic field inclinations and viscous dissipation due to heat generation or absorption parameter on MHD mixed convective flow of Casson nanofluid. They found that with an increase in Casson parameter, the velocity field is suppressing, in parallel with an increase in Casson parameter temperature raised. A work was done by Govardhan et al. [6] on heat transfer with MHD Casson fluid flow towards a linear stretching sheet with temperature distribution over the sheet. The authors found out that solution depends on Brownian motion number, thermophoresis number, Prandtl number. Sime recent studies on heat transfer and nanofluid flows are presented in Elelamy, A.F. et al. [7], M.A. Yousif et al. [8] and Zeeshan, A. et al. [9] did a piece of work on nanofluid in a stretching sheet in which MHD flow is investigated. The problem was solved by a numerical technique.

Besides, the study of magnetohydrodynamic flow has gained the attention of modern era scientists on account of its extensive industrial and engineering application. Such applications incorporate the design of cooling frameworks by including liquid metals, MHD generators, petroleum industries, accelerators, nuclear reactors, energy stockpiling, pumps, gas turbines and flow meters. Having such an idea as a top priority the scientists and mathematician investigated the behavior of MHD flows in different physical angles. Sheikholeslami et al. [10] scrutinized the properties of magnetohydrodynamic nanofluid. The method employed by the authors is the lattice Boltzmann method. The MHD flow of nanofluid provoked by a stretching surface was examined by Rashidi et al. [11]. They found that magnetic fields lead to decrease the nanofluid velocity and increase the nanofluid temperature. Zeeshan et al. [12] inspected the results of magnetic dipole on ferrofluid. They discussed the problem physically for various flow problems. Hayat et al. [13] inspected the consequences of Jeffrey fluid model with convective boundaries. Narender et al. [14] examined the viscous dissipation and thermal radiation effects on the MHD mixed convection stagnation point flow of Maxwell nanofluid over a stretching surface. In this area, various studies have been performed [15,16].

Thermal radiation is conducted through electromagnetic waves. The energy is transferred due to temperature difference between the two surfaces. In this process the energy is spread in the form of waves in all directions. The emission of these radiations depends on temperature surface, nature of surface and frequency of radiations. If the temperature difference is small then linear thermal radiation is applicable, however if the difference of temperature is large then linear thermal radiation is not applicable. In recent years, many researchers focused on the utilization of magnetohydrodynamics along with the thermal radiation phenomenon to study the heat and mass transfer analysis due to its diversified applications. S. Shah et al. presented numerical analysis of Cattaneo-Christov heat flux model for MHD flow of Maxwell fluid with thermal radiation [17].

The Shooting method and the MATLAB built in routine bvp4c applied for computing solutions. The thermal characterization of two-dimensional Maxwell nanofluid flow over a permeable stretching sheet using the finite element method was investigated by Madhu et al. [18]. Thermal radiation influences in various fluids with the imposition of different conditions is studied by Endalew and Nayak [19].

The chemical reaction stimulus a great role in the investigation involving heat and mass in areas of science and engineering technology. Zhang et al. [20] studied the effects of chemical reaction and thermal radiation on nanofluids of heat transfer through the porous medium. Sarma et al. [21] considered the problem as a boundary layer flow over a stretching sheet with chemical reaction.

A chemical reaction between the conventional liquid and nanoparticles are classified as a homogeneous reaction during a given phase or heterogeneous reaction i.e., surrounded by a boundary of phase. Reaction rate in the first order chemical reaction is straightly related to the concentration. Several authors examined the effect of chemical reaction on nanofluids of heat transfer over a stretching sheet [22 – 24].

The novelty of the present study rests upon the following. The study takes care of the

nanofluid flow with Cassion fluid as the base fluid and suspended nanoparticles. Important mechanisms such as thermophoresis and Brownian motion effect emphasizes the nanoparticle characteristics. The existing model is mathematically formulated to the system of nonlinear partial differential equations and converted into system of coupled nonlinear nonlinear ordinary differential equations via similarity invariants. A numerical solution of the system of ODEs is obtained by employing the shooting method and Adams Moulton method of fourth order the precision of the obtained numerical results is compared by using the computational program FORTRAN code. The objective is to simulate the effect of important parameters on flow, heat, and mass transfer phenomena. To the best of the authors knowledge, this is the first study to investigate a mathematical model with numerical simulation.

2. Mathematical Modelling

Consider the 2-D stagnation point flow of MHD Casson fluid over a stretching surface under the impact of slip wall. Magnetic field of strength is applied B_0 perpendicular to the fluid motion. Additionally, the impacts of Brownian motion and thermophoretic diffusion are also considered. Furthermore, the equations of energy and mass transport are known to determine the profiles of heat and concentration, respectively. At $x-$axis the stretching sheet is taken and $y-$axis is normal to the plate that can be seen in Figure 1. The stretching and slip velocities at the boundary are taken as $U_w(x) = a\,x$ and $U_{slip} = \left(\mu_B + \dfrac{P_y}{\sqrt{2\pi_c}} \right)\dfrac{\partial u}{\partial y}$ respectively, where p_y denotes the yield stress, T_w is the surface temperature, μ_B is the plastic dynamic viscosity, π_c represents the critical value of product, $U_\infty = b\,x, T_\infty, C_\infty$ represent the free stream velocity, temperature, and concentration.

Governing Equations:

The elementary governing equations are shown as follows for the two-dimensional incompressible Casson nanofluid [25]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$\left. \begin{array}{l} u\,\dfrac{\partial u}{\partial x} + v\,\dfrac{\partial u}{\partial y} = \nu\left(1+\dfrac{1}{\gamma}\right)\dfrac{\partial^2 u}{\partial y^2} + U_\infty\,\dfrac{\partial U_\infty}{\partial x} \\[2mm] \qquad + \dfrac{\sigma B_0^{\,2}}{\rho_f}(U_\infty - u), \end{array} \right\} \tag{2}$$
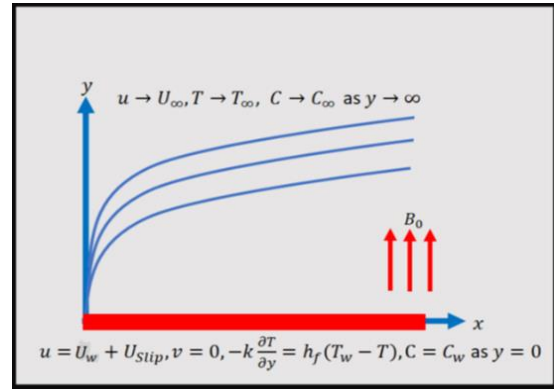
Fig. 1. Geometrical view of the Physical mode.

$$\left. \begin{array}{l} u\,\dfrac{\partial T}{\partial x} + v\,\dfrac{\partial T}{\partial y} = \alpha\,\dfrac{\partial^2 T}{\partial y^2} + \Gamma\left\{ D_B\,\dfrac{\partial C}{\partial y}\dfrac{\partial T}{\partial y} + \dfrac{D_T}{T_\infty}\left(\dfrac{\partial T}{\partial y}\right)^2 \right\} \\[3mm] \qquad - \dfrac{1}{(\rho C)_f}\dfrac{\partial q_r}{\partial y} + \dfrac{\nu}{C_p}\left(1+\dfrac{1}{\gamma}\right)\left(\dfrac{\partial u}{\partial y}\right)^2, \end{array} \right\} \tag{3}$$

$$\left. \begin{array}{l} u\,\dfrac{\partial C}{\partial x} + v\,\dfrac{\partial C}{\partial y} = D_B\,\dfrac{\partial^2 C}{\partial y^2} + \dfrac{D_T}{T_\infty}\,\dfrac{\partial^2 T}{\partial y^2} \\[3mm] \qquad - K^\bullet\,(C - C_\infty). \end{array} \right\} \tag{4}$$

The related BCs can be described as [25]:

$$\left. \begin{array}{l} \text{Wall conditions}\,(y=0): \\[2mm] u = U_w(x) + U_{Slip} \Rightarrow u = ax + \left(\mu_B + \dfrac{P_y}{\sqrt{2\pi_c}}\right), \\[3mm] v = 0, -k\,\dfrac{\partial T}{\partial y} = h_f\,(T_f - T), C = C_w. \\[4mm] \text{Free stream conditions}\,(y \to \infty): \\[2mm] u \to U_\infty = b\,x, v = 0, T \to T_\infty, C \to C_\infty. \end{array} \right\} \tag{5}$$

here, u and v represent the velocity elements in the direction of $x-$axis and $y-$axis respectively, ρ_f is the fluid density, σ denotes the electrical conductivity, T represents the temperature, α is the thermal diffusivity, Γ represents the relation among heat capacity of the antiparticle and the liquid, C is the concentration parameter, μ_B represents the dynamic viscosity, p_y denotes the yield stress, π_c represents the critical value of product and a, b are positive constants. As the heat flux is transported to the body as conduction, the following boundary condition holds good.

$$-k\,\frac{\partial T}{\partial y} = h_f\left(T_f - T\right)$$

Here, k denotes the thermal conductivity, h_f denotes the coefficient of heat transfer.

3. Similarity Transformation

The following similarity variables for translation of PDEs into ODEs have been added here.

$$\left.\begin{array}{ll} \eta = y\sqrt{\dfrac{a}{\nu}}, & \psi = \sqrt{a\,\nu}\,x\,f\,(\eta), \\[12pt] \theta(\eta) = \dfrac{T-T_\infty}{T_w-T_\infty}, & \phi(\eta) = \dfrac{C-C_\infty}{C_w-C_\infty}. \end{array}\right\} \quad (6)$$

The above, equation (1) is satisfied identically. The equations take the form after employing similarity transformation.

$$\left(1+\frac{1}{\gamma}\right)f''' + ff'' - \left(f'\right)^2 + A^2 + M\left(A - f'\right) = 0, \ (7)$$

$$\left(1+\frac{4}{3R}\right)\theta'' + \Pr\left(\begin{array}{l} f\theta' + Ec\left(1+\dfrac{1}{\gamma}\right)\left(f''\right)^2 \\[8pt] + Nb\,\phi'\,\theta' + Nt\left(\theta^1\right)^2 \end{array}\right) = 0, \ (8)$$

$$\phi'' + Le\,\Pr\,\phi' + \frac{Nt}{Nb}\theta'' - Le\,Kr\,\phi = 0. \qquad (9)$$

The dimensionless conditions associated with the boundary are as follows:

$$\left.\begin{array}{l} f(\eta) = 0, \\[6pt] f'(\eta) = 1 + \delta\left(1+\dfrac{1}{\gamma}\right)f''(\eta), \\[8pt] \theta'(\eta) = -Bi\left[1 - \theta(\eta)\right], \\[6pt] \phi(0) = 1 \end{array}\right\},at\ \eta = 0, \\ \left.\begin{array}{l} f'(\eta) \to A, \quad \theta(\eta) \to 0, \\[6pt] \phi(\eta) \to 0 \end{array}\right\}as\ \eta \to \infty \qquad (10)$$

in the above equation δ momentum slip parameter, A the ratio of stretching velocity of free stream and lower plate. The temperature field is dependent on Biot number (Bi) when the heat transfer takes places into the fluid.

The following expression refers to different parameters used in the above equations [20]:

$$\left.\begin{array}{l} Bi = \dfrac{h_f}{k}\sqrt{\dfrac{\nu}{a}}, \ R = \dfrac{4\sigma^*T_\infty^3}{k_0 k}, M = \dfrac{\sigma B_0^2\,(x)}{\rho_f a}, \\[12pt] Ec = \dfrac{u^2}{C_p\left(T_f - T_\infty\right)}, \ A = \dfrac{b}{a}, \ \delta = \mu_B\sqrt{\dfrac{a}{\nu}} \\[12pt] Nb = \dfrac{(\rho C)_p}{(\rho C)_f\,\nu}D_B\left(C_w - C_\infty\right), \ L_e = \dfrac{\alpha}{D_B} \\[12pt] Nt = \dfrac{(\rho C)_p}{(\rho C)_f\,\nu}D_T\left(T_w - T_\infty\right), \ \Pr = \dfrac{\nu}{\alpha}. \end{array}\right\} \quad (11)$$

The physical quantities which govern the flow are the Nusselt number (Nu_x), Sherwood number (Sh_x) and skin friction coefficient (C_f), which are given by,

$$\left.\begin{array}{l} Nu_x = \dfrac{xq_w}{k\left(T_w - T_\infty\right)}, \\[12pt] Sh_x = \dfrac{xh_m}{D_B}(C_w - C_\infty), \qquad C_f = \dfrac{\tau_w}{\rho u_w^2} \end{array}\right\} \quad (12)$$

where heat, mass flux at the surface are q_w and h_m respectively defined as $q_w = -k\left(\dfrac{\partial T}{\partial y}\right)$, $h_m = -D_B\left(\dfrac{\partial \phi}{\partial y}\right)$ and the skin - friction on flat plate τ_w is given by $\tau_w = \left(\mu_B + \dfrac{p_y}{\sqrt{2\pi}}\right)\left(\dfrac{\partial u}{\partial y}\right)$.

Using the similarity transformations, we obtain:

$$\left.\begin{array}{l} C_f\,\mathrm{Re}_x^{\frac{1}{2}} = \delta\left(1+\dfrac{1}{\gamma}\right)f'', \\[12pt] \dfrac{Nu_x}{\sqrt{\mathrm{Re}_x}} - \theta'(0), \qquad \dfrac{Sh_x}{\sqrt{\mathrm{Re}_x}} - \phi'(0). \end{array}\right\} \quad (13)$$

here, $\mathrm{Re}_x = \dfrac{U_w x}{\nu}$ is the local Reynold number.

4. Solution Approach

Numerous analytical and numerical techniques, including the homotopy perturbation method, homotopy analysis method, optimised homotopy analysis method, adomian decomposition method, finite difference method, finite element method, etc., can be used to solve the resulting non-linear system of ODEs. We chose the shooting method, a well-known numerical methodology that is an effective strategy in terms of processing time.

The shooting approach has been used to find solutions for various values of the parameters involved in the system of nonlinear ODEs (7–9) subject to boundary constraints (10). Basically, equation (7) is solved numerically and afterward the computed results of f, f' and f'' are used in equations (8)-(9). For the numerical treatment of equation (7), the missing initial condition $f''(0)$ has been denoted as p and the following notations have been considered.

$$\left.\begin{array}{l} f = g_1, f' = g_1' = g_2, f'' = g_1'' = g_2' = g_3, \\[8pt] \dfrac{\partial f}{\partial p} = g_4, \ \dfrac{\partial f'}{\partial p} = g_5, \ \dfrac{\partial f''}{\partial p} = g_6. \end{array}\right\} \quad (14)$$

The equation (7) can be translated into a scheme of three first-order ODEs using the upward notations. The reduced form of equation (7) is the first three of the ODEs and the remaining three are taken by differentiating the first three w.r.t p.

$$g_1' = g_2, \qquad\qquad g_1(0) = 0,$$

$$g_2' = g_3, \qquad\qquad g_2(0) = 1 + \delta\left(1 + \frac{1}{\gamma}\right)g,$$

$$g_3' = -\frac{1}{\left(1 + \frac{1}{\gamma}\right)}\left[g_2^2 + A^2 - g_1 g_3 - M\left(A - g_2\right)\right],$$

$$g_3(0) = p,$$

$$g_4' = g_5, \qquad\qquad g_4(0) = 0,$$

$$g_5' = g_6, \qquad\qquad g_5(0) = \delta\left(1 + \frac{1}{\gamma}\right),$$

$$g_6' = \frac{1}{\left(1 + \frac{1}{\gamma}\right)}\left[2g_2 g_5 - g_4 g_3 - g_1 g_6 + M g_5\right],$$

$$g_6(0) = 1,$$

To solve the above initial value problem with Adam's Moulton method of order four, we must take some initial guesses for p. The missing condition for the above system of equations is to be picked to such an extent that $\left(g_2(\infty)\right)_p = A$. Newton's method is utilized to improve these original estimates.

$$p^{(n+1)} = p^{(n)} - \frac{\left(g_2(\eta_\infty)\right)_{g=g^{(n)}} - A}{\left(\frac{\partial g_2(\eta_\infty)}{\partial p}\right)_{p=p^{(n)}}}, \qquad (15)$$

The following benchmark is achieved,

$$\left|g_2(\eta_\infty) - A\right| < \varepsilon, \qquad\qquad (16)$$

To solve the equations (8) and (9), it is converted into the following system of the first order differential expressions and f as a known function. The following notations were therefore taken into consideration.

$$\left.\begin{array}{l}\theta = y_1, \theta' = y_2, \phi = y_3, \phi' = y_4, \dfrac{\partial\theta}{\partial s} = y_5, \\[2mm] \dfrac{\partial\theta'}{\partial s} = y_6, \dfrac{\partial\phi}{\partial s} = y_7, \dfrac{\partial\phi'}{\partial s} = y_8, \dfrac{\partial\theta}{\partial t} = y_9, \\[2mm] \dfrac{\partial\theta'}{\partial t} = y_{10}, \dfrac{\partial\phi}{\partial t} = y_{11}, \dfrac{\partial\phi'}{\partial t} = y_{12}.\end{array}\right\} \quad (17)$$

The following resulting system of equations is achieved:

$$\left.\begin{array}{ll} y_1' = y_2, & y_1(0) = s, \\[2mm] y_2' = \dfrac{-\Pr}{\left(1 + \frac{4}{3R}\right)}\left[\begin{array}{l} f\, y_2 + Nb\, y_2\, y_4 + \\ Nt\, y_2^2 + Ec\left(1 + \frac{1}{\gamma}\right)\left(f''\right)^2 \end{array}\right], & \\[3mm] & y_2(0) = -Bi(1-s), \\[2mm] y_3' = y_4, & y_3(0) = 1, \\[2mm] y_4' = -Le\,\Pr f\, y_4 - \dfrac{Nt}{Nb} y_2' + Le\, Kr\, y_3, & \\[2mm] & y_4(0) = t, \\[2mm] y_5' = y_6, & y_5(0) = 0, \\[2mm] y_6' = \dfrac{-\Pr}{\left(1 + \frac{4}{3R}\right)}\left[\begin{array}{l} f\, y_6 \\ + Nb\left(y_4\, y_6 + y_2\, y_8\right) \\ + 2\, Nt\, y_2\, y_6 \end{array}\right], & \\[3mm] & y_6(0) = B_i, \\[2mm] y_7' = y_8, & y_7(0) = 0, \\[2mm] y_8' = -Le\,\Pr f\, y_8 - \dfrac{Nt}{Nb} y_6' + Le\, Kr\, y_7, & \\[2mm] & y_8(0) = 0, \\[2mm] y_9' = y_{10}, & y_9(0) = 0, \\[2mm] y_{10}' = \dfrac{-\Pr}{\left(1 + \frac{4}{3R}\right)}\left[\begin{array}{l} f\, y_{10} + \\ Nb\left(y_4\, y_{10} + y_2\, y_{12}\right) \\ + 2\, Nt\, y_2\, y_{10} \end{array}\right], & \\[3mm] & y_{10}(0) = 0, \\[2mm] y_{11}' = y_{12}, & y_{11}(0) = 0, \\[2mm] y_{12}' = -Le\,\Pr f\, y_{12} - \dfrac{Nt}{Nb} y_{10}' + Le\, Kr\, y_{11}, & \\[2mm] & y_{12}(0) = 1, \end{array}\right\} \quad (18)$$

Now eq. (18) can solve numerically with the help of Shooting technique along with Adam's-Moulton method. To get the approximate solution, the domain of the problem has been taken as $[0, \eta_\infty]$ instead of $[0, \infty)$, where η_∞ is an appropriate finite positive real number. In the above system of equations, the missing conditions s and t, must be chosen in such a way that,

$$h_2(\eta_\infty, s, t)_s = 0, \qquad h_4(\eta_\infty, s, t)_s = 0 \quad (19)$$

For the improvement of the missing condition, Newton's method has been implemented which is conducted by the following iterative scheme:

$$\begin{bmatrix} s^{(k+1)} \\ t^{(k+1)} \end{bmatrix} = \begin{bmatrix} s^{(k)} \\ t^{(k)} \end{bmatrix} - \begin{bmatrix} \begin{bmatrix} h_7 & h_9 \\ h_{11} & h_{14} \end{bmatrix}^{-1} \begin{bmatrix} h_2 \\ h_4 \end{bmatrix} \end{bmatrix}_{\left(s^{(k)},t^{(k)},\eta_\infty\right)} \quad (20)$$

The following steps are involved for the accomplishment of the shooting method.

(i). Choice of the guesses $s = s^{(0)}$ and $t = t^{(0)}$

(ii). Choice of a positive small number ε.

If $\max\left\{\left|\left(y_1\left(\eta_\infty\right)\right)\right|, \left|\left(y_3\left(\eta_\infty\right)\right)\right|\right\} < \varepsilon$, the process is terminated, otherwise go to (iii)

(iii). Compute $r^{(k+1)}$ and $s^{(k+1)}$, $k = 0,1,2,..$ by using equation (20).

(iv). Repeat (i) and (ii).

All through this article, ε has been taken as 10^{-12} while η_∞ is set as 7.

5. Analysis of Results

This section addresses the numerical solutions in detail, using graphs and tables. This will primarily address the velocity, temperature, and concentration profile. The present results will be compared with those of [20] for verification of the code. The numerical calculations are executed for the observation of the impact of various parametric values of γ, δ, A, Bi, Nb, Nt, Le, Kr on velocity, temperature, mas fraction field.

In Table 1, comparison of Skin Friction Coefficient $-f''(0)$ for different values of δ is displayed. The results were compared with those obtained by Hayat et al. [13] and Ibrahim and Makinde. [20] and found both to be in excellent agreement. From table 1 it is observed that skin friction coefficient is decreased by increase of slip parameter.

Table 2 shows the skin-friction coefficient $-f''(0)$ decreases by the increase of A. The effect of δ on Nusselt number $-\theta'(0)$ decreases and Sherwood number $-\phi'(0)$ is opposite as compared to Nusselt number.

Table 1. Comparison of the values of Skin Friction Coefficient $-f''(0)$ those from Ibrahim and Makinde [25].

δ	Hayat et al. [13]	Ibrahim and Makinde [25]	Present study
0.0	1.000000	1.0000	0.9999855
0.1	0.872082	0.8721	0.8720812
0.2	0.776377	0.7764	0.7763964
0.5	0.591195	0.5912	0.5912748
2.0	0.283981	0.2840	0.2841796
5.0	0.144841	0.1448	0.1450588
10.0	0.081249	0.0812	0.0814330
20.0	0.043782	0.0438	0.0439329
50.0	0.018634	0.0186	0.0186789

Table 2. Comparison of numerical values of Skin Friction coefficient $-f''(0)$, Local Nusselt number $-\theta'(0)$ and Local Sherwood number $-\phi'(0)$ those from Ibrahim and Makinde [25].

A	δ	γ	$-f''(0)$ Ibrahim and Makinde [25]	$-f''(0)$ Present study	$-\theta'(0)$ Ibrahim and Makinde [25]	$-\theta'(0)$ Present study	$-\phi'(0)$ Ibrahim and Makinde [25]	$-\phi'(0)$ Present study
0.0	0.1	10	1.1451	1.1414830	0.0922	0.0921669	2.0435	2.0434700
0.1			1.0653	1.0653210	0.0923	0.0923036	2.0849	2.0848620
0.2			0.9792	0.9791939	0.0924	0.0924430	2.1283	2.1282550
0.3			0.8838	0.88382410	0.0926	0.0925826	2.1730	2.1730430
0.9			0.1467	0.1466890	0.0934	0.0933622	2.4534	2.4533620
1.5			-0.818	-0.8188152	0.0940	0.0940005	2.7333	2.7333010
2.0			-1.762	-1.7622860	0.0944	0.0944359	2.9597	2.9597170
2.4			-2.594	-2.5944010	0.0947	0.0947337	3.1356	3.1356140
0.4	0.2		0.6758	0.6757960	0.0925	0.0924937	2.1478	2.1477870
	0.4		0.5357	0.5356795	0.0921	0.0921433	2.0464	2.0464120
	0.6		0.4449	0.4449050	0.0919	0.0918827	1.9768	1.9767530
	0.8		0.3810	0.0934260	0.0917	0.0916797	1.9256	1.9255770
	0.4	0.1	0.0908	0.0907876	0.0916	0.0915679	1.9015	1.9014960
		0.5	0.2563	0.2563434	0.0920	0.0919709	2.0018	2.0018460
		1	0.3477	0.3477455	0.0921	0.0920584	2.0246	2.0245580
		10	0.5357	0.5356796	0.0921	0.0921433	2.0464	2.0464120
		100	0.5688	0.5688785	0.0921	0.0921503	2.0482	2.0481280

Table 3. Behaviour of $-f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for variable values of A, δ, γ, Nb, Nt, Pr, Le, Bi, M.

A	δ	γ	Nb	Nt	Pr	Le	Bi	M	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.0	0.1	10	0.1	0.1	10	10	0.1	1.0	1.1415110	0.08939873	7.211071
0.1									1.0653300	0.08959904	7.270552
0.2									0.9791964	0.08980191	7.336496
0.3									0.8838250	0.09000381	7.408033
0.9									0.1466889	0.09113192	7.920059
1.5									-0.8188149	0.09200104	8.511965
2.0									-1.7622840	0.09259528	9.032217
2.4									-2.5944000	0.09301120	9.456006
0.4	0.2								0.67579670	0.08990348	7.230251
	0.4								0.53567970	0.08944395	6.864066
	0.6								0.44490520	0.08910342	6.609847
	0.8								0.38096870	0.08883907	6.421543
	0.4	0.1							0.09215718	0.08866987	6.154168
		0.5							0.25656680	0.08923871	6.594784
		1							0.34781170	0.08934746	6.712249
		10							0.53568420	0.08944392	6.864055
		100							0.56880820	0.08945096	6.883239

Table 3 shows the numerical results of the skin-friction coefficient along with the Nusselt and Sherwood numbers for the current model in respect of a shift in the values of various parameters such as A, δ, γ, Nb, Nt, Pr, Le, Bi, M. From the results, it was noted that the skin-friction coefficient decreases for the larger values of A and δ, while heat and mass transfer rates increase significantly.

Figure 2 is drawn to investigate the effect of Casson parameter on the velocity filed. The fluid velocity increases with an increasing value of Casson parameter (γ). Physically, the consistency of the fluid increments due to the escalation of γ the values and then decreases, the fluid's velocity profile also decreases the velocity boundary layer thickness for uprising values of Casson parameter (γ). Furthermore, the present phenomenon changes to Newtonian fluid when γ tends to infinity.
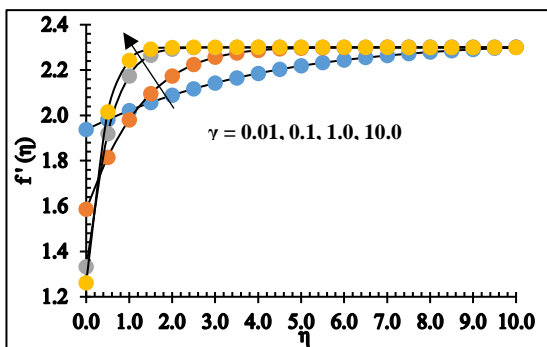
Fig. 2. Influence of Casson parameter on axial velocity profile when $\delta = 0.1, A = 2.3, M = 1$.

Figure 3 reveals the impact of Casson Parameter (γ) on temperature distribution. The escalating values of γ by which the mounting values of temperature depiction. Generally, the thermal boundary layer depth uprise by increasing values of γ due to which the surface temperature enlarges with.
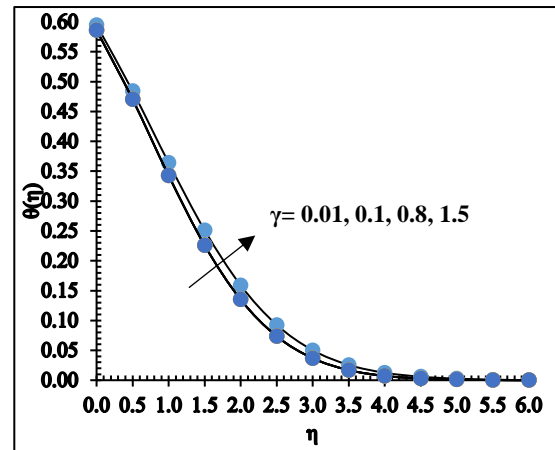
Fig. 3. Influence of Casson parameter on temperature profile when $Nt = Nb = 0.5, Le = 2, A = 0.4$, Pr $= M = 1$
$Bi = 0.5, \delta = R = Ec = 0.2$,

Figure 4 indicates the impact of δ on the distribution of dimensionless velocity. It is clearly shown that by an enhancing value of the velocity profile arises. Generally, the growing values of δ create a frictional resistance between the surface of the sheet and fluid particles escalates, which causes a decrement of the fluid velocity.
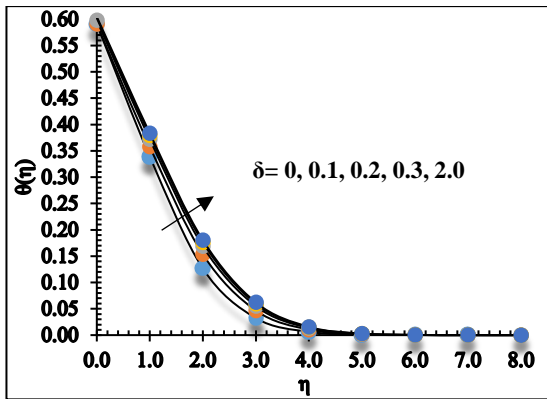
Fig. 4. Influence of momentum slip on axial velocity profile when $\gamma = 0.1, A = 0.4, M = 1$.

Figure 5 illustrates the influence of δ on temperature distribution, from the figure it is apparent that especially for cautiously enlarging values of δ, the temperature field is enhanced. Increasing the values of δ the thermal boundary layer depth also raises the sheet surface temperature.
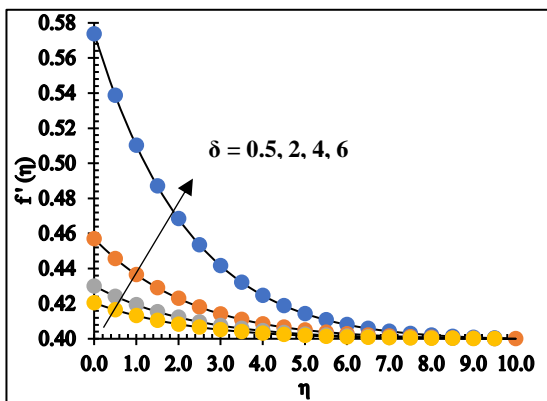
Fig. 5. Impact of momentum slip on temperature profile when $Nt = Nb = 0.5, Le = 2, \gamma = 0.1, Bi = 0.5,$ $R = Ec = 0.2, \Pr = M = 1, A = 0.4.$

Figure 6 analyses the effect of A on the distribution of dimensionless velocity. From the figure it is apparent that when the free stream velocity is greater than the surface velocity, while the fluid particle velocity accelerates at $A > 1$. In addition, the thickness of the boundary layer decelerates by increasing the A values. In fact, if the stretching velocity is less than the free-stream velocity the velocity graph tends to be A. Often, when the extending sheet velocity is greater than the free-stream velocity, which creates a fluid velocity declaration.

Figure 7 displays the effect of A on temperature distribution. As the value A heightens, the heat transfer from the sheet to the fluid become smaller and as a result, the temperature falls significantly. Furthermore the thermal boundary layer thickness id reduced.
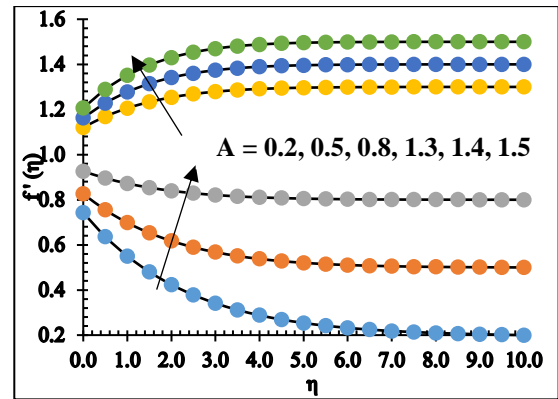
Fig. 6. Impact of A on axial velocity profile when $\gamma = 0.1, \delta = 0.1, M = 1.$
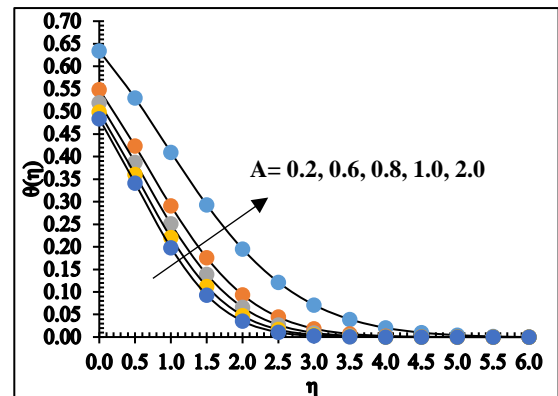
Fig. 7. Influence of on temperature profile when $Le = 2$, $Nt = Nb = 0.5, \ \gamma = 0.1, Bi = 0.5, \delta = R = E_C = 0.2, \Pr = M = 1.$

Figure 8 reflects the influence of Boit number on the dimensionless temperature distribution. The graph of the velocity profile specifies that an increment in Bi causes an enhancement in the temperature profile. Generally, Biot number is expressed as the ratio of temperature change at the surface to conduction within the surface of the body. As expected, the boosting values of Bi enhanced the thermal boundary layer of the fluid.
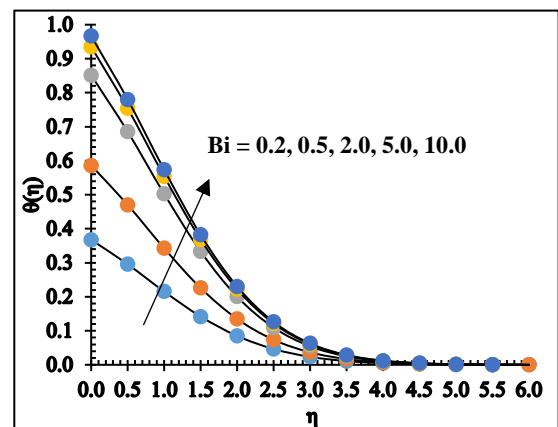
Fig. 8. Influence of temperature slip on temperature profile when $Nt = Nb = 0.5, Le = 2, \gamma = 0.1, \Pr = M = 1,$ $\delta = 0.2, A = 0.4.$

Figure 9 manifests the relationship between Bi (Biot number) and the concentration profile. For boosting values of Biot number the graph of dimensionless concentration profile is increased. Increasing Bi means a decrement in the fluid's conductivity because of which the boundary layer of concentration is increased.
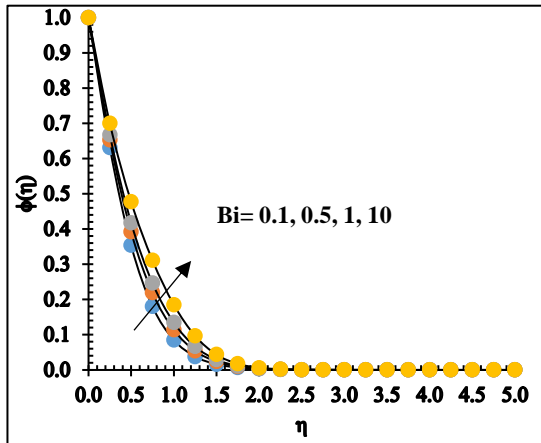
Fig. 9. Influence of Biot number on nanoparticle volume fraction profile when $Nt = Nb = 0.1, \mathrm{Pr} = 5, A = 0.4, \; \delta = 0.1, \gamma = R = Ec = 0.2, Le = M = 1.$

Figure 10 illustrates the Nt effect on temperature distribution. From the figure it is transparent that the $\theta(\eta)$ field is improved for moderately enlarging values of Nt. In addition, the particles Nt apply a force on the other particles because of which these particles shift from the hotter to less region. Therefore, there is an intensification of the fluid's $\theta(\eta)$ profile.
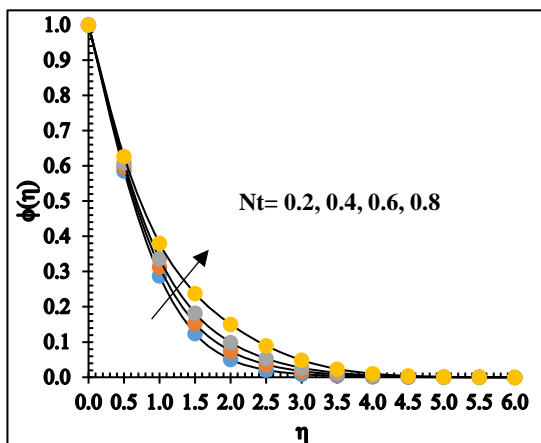
Fig. 10. Influence of Nt on temperature profile when $Nb = 0.5, Le = 2, \gamma = 0.1, Bi = 0.5, \delta = R = Ec = 0.2,$ $\mathrm{Pr} = M = 1, \quad A = 0.4.$

Figure 11 illustrates the impact of Nt on concentration distribution, from the figure for

gradually enlarging values of Nt the concentration field is enhanced.
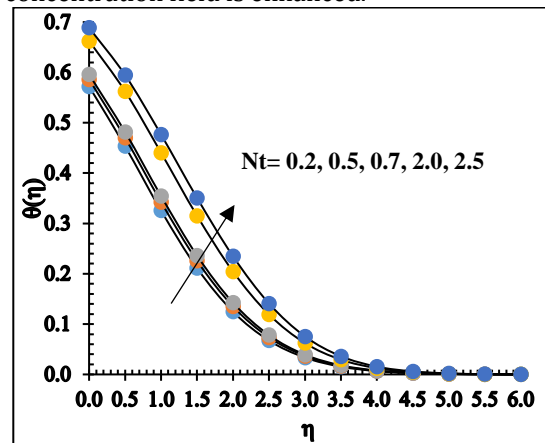
Fig. 11. Influence of Nt on nanoparticle volume fraction profile when $Nb = 0.1, \mathrm{Pr} = 5, A = 0.4, \delta = 0.1, Le = M = 1,$ $Bi = \gamma = R = Ec = 0.2.$

Figure 12 analyses the impact of Brownian motion parameter on the temperature distribution. The temperature profile climbs marginally for the large values of Nb. This happens due to the reason that as the value of Brownian motion parameter rises, the movement of the nanoparticle enhances significantly which triggers the kinetic energy of the nanoparticles and eventually, the temperature enhances, and thermal boundary layer thickness is magnified.
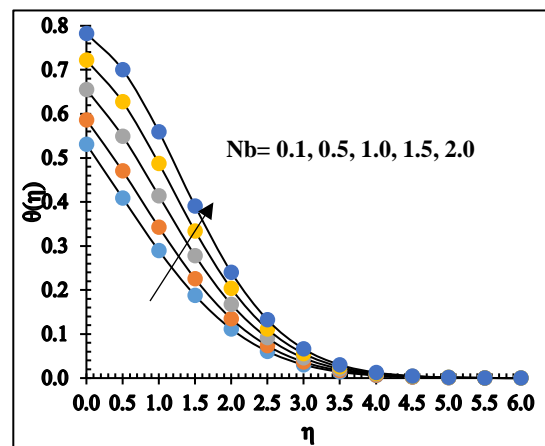
Fig. 12. Influence of Nb on temperature profile when $Nt = 0.5, Le = 2, \gamma = 0.1, Bi = 0.5, \delta = R = Ec = 0.2,$ $\mathrm{Pr} = M = 1, A = 0.4.$

Figure 13 shows the connection between Lewis numbers and the dimensional concentration distribution. Concentration profile decelerates for the boosting values of Lewis number (Le), physically Lewis number express the respective contribution of rate of thermal diffusion to the rate of species diffusion on the

boundary region. As increasing values of Lewis number (Le).

Figure 14 portrays the impact of Eckert number on the temperature field. It is noticed that there is a gradual decrease in the fluid energy by an increment in Ec. Here, it is observed that the temperature increases for gaining the values of Ec. Physically, the Eckert number depicts the relation between the kinetic energy of the fluid particles and the boundary layer enthalpy. The kinetic energy of the fluid particles rises as Ec assume the large values. Hence, the temperature of the fluid climbs marginally and therefore, the associated thermal boundary layer thickness is enhanced.

provides additional heat to the operating fluid which amplifies the temperature field.

Figure 16 shows the effects of chemical reaction parameter on the concentration field $\phi(\eta)$. It is noticed that Increasing values of chemical reaction parameter concentration as well as the thickness of concentration decreases. It is because of the fact that the chemical reaction in this system results in chemical dissipation and therefore results in decreases in the profile of concentration. The most significant influence is that chemical reaction tends to decrease the overshoot in the concentration profile and their associated boundary layer.

Fig. 13. Influence of Lewis number on nanoparticle volume fraction profile when $Nt = Nb = Bi = 0.1, \Pr = 5, \quad \delta = 0.1,$ $A = 0.4, \quad \gamma = R = Ec = 0.2, M = 1.$
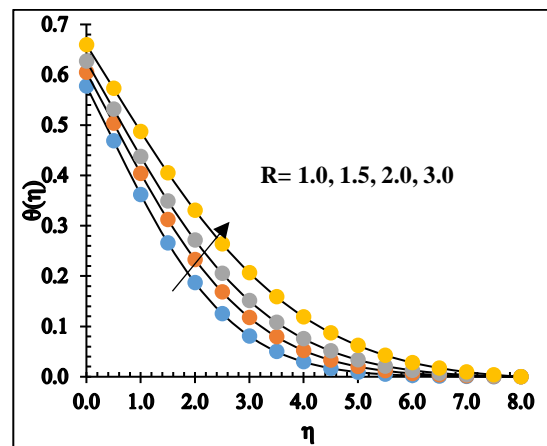
Fig. 15. Influence of Radiation parameter on temperature profile when $Nt = Nb = 0.2 \Pr = 5, A = 0.4, \delta = 0.1, \quad Bi = 0.2,$ $\gamma = Ec = 0.2, Le = M = 1.$

Fig. 14. Influence of Eckert number on temperature profile when $Nt = Nb = 0.2 \Pr = 5, A = 0.4, \delta = 0.1, Bi = 0.2,$ $\gamma = R = 0.2, \quad Le = M = 1.$
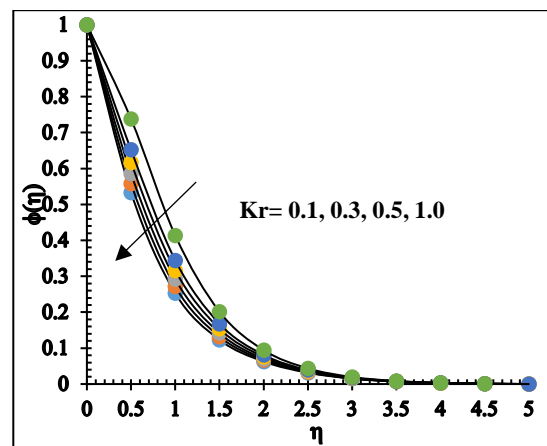
Fig. 16. Influence of Chemical reaction on nanoparticle volume fraction profile when $Nt = Nb = 0.2, \Pr = 0.5,$ $A = 0.4, \delta = 0.1, Bi = \gamma = Ec = 0.2, Lr = M = 1, R = 0.2.$

6. Conclusions

This article presented numerical simulations of boundary layer flow of Casson nanofluid over a linear stretching sheet in the presence of chemical reaction with slip conditions on the flow field. We applied suitable similarity

Figure 15 is sketched for the investigation of the temperature profile in response to the thermal radiation parameter R. By increasing the thermal radiation, increase in temperature profile is observed. Physically, a magnification in

transformations to reduce the complex governing equations into a set of ODEs. The numerical solutions are obtained by using the shooting method with Adams Moulton method. Our results are excellent agreement with the existing numerical literature results. Different physical parameters are inspected on fluid flow: heat transfer and mass transfer characteristics. In light of the numerical results, the following keynotes are made.

- The fluid velocity declines with increasing values of Casson and slip parameter.

- The fluid energy accelerates effectively with an increase in the Biot number.

- The temperature distribution enhances effectively with uprising values of Brownian motion and thermophoresis parameters.

- Concentration profile decelerates for the boosting values of Lewis number and thus we get a small molecular diffusivity and thermal boundary layer.

- Fluid concentration and associative boundary thickness are increasing functions of Casson parameter.

- The thermal boundary layer thickness increases for the rise of Eckert number (Ec) as well as radiation parameter (R).

- Higher values of chemical reaction (Kr) leading to a reduction in nanoparticle concentration.

- It is noted that Nu_x is also increased by enhancing the values of Lewis number (Le).

- The problem can be extended for stretching surface in different types of fluids for instance Maxwell nanofluid Carreau nanofluid.

- Different numerical techniques can be utilized to solve fluid flow problems.

Nomenclature

The following symbols are used in this paper:

$a,\ b$ Stretching constant $\left(s^{-1}\right)$

B_0 Magnetic field strength $\left(Wbm^{-2}\right)$

D_B Brownian diffusion coefficient

D_T Thermophoretic diffusion coefficient

κ Thermal conductivity $\left(Wm^{-1}K^{-1}\right)$

$\sigma^{\bullet}$ Stefan-Boltzmann constant $\left(kg\ m^{-2}K^{-4}\right)$

$\kappa^{\bullet}$ Mean absorption coefficient

Ec Eckert number

Le Lewis number

M Magnetic parameter

N_b Brownian motion parameter

N_t Thermophoresis parameter

Nu Nusselt number

Nu_x Reduced Nusselt number

$\Pr$ Prandtl number

$\wp$ Pressure

c_f Heat capacity of the fluid $\left(Jm^{-3}K^{-1}\right)$

c_p Effective heat capacity of the nanoparticle material $\left(Jm^{-3}K^{-1}\right)$

q_r Radiative heat flux $\left(kg\ m^{-2}\right)$

q_m Wall mass flux $\left(W\,m^{-2}\right)$

q_w Wall heat flux $\left(W\,m^{-2}\right)$

Re_x Local Reynolds number

Shr Reduced Sherwood number

Sh_x Local Sherwood number

T Fluid temperature (K)

T_w Temperature at the stretching sheet (K)

T_∞ Ambient temperature (K)

u, v Velocity components along $x-$ and $y-$ axis $\left(m.s^{-1}\right)$

u_w Velocity of the stretching sheet $\left(m.s^{-1}\right)$

x, y Cartesian coordinates ($x-$ axis is aligned along the stretching surface and $y-$ axis is normal to it) (L)

$\propto$ Thermal diffusivity $\left(m^2\ s^{-1}\right)$

ϕ Dimensionless nanoparticle volume fraction

η Similarity variable

ψ Stream function $\left(m^2\ s^{-1}\right)$

θ Dimensionless temperature

ρ_f Fluid density $\left(kg\ m^{-3}\right)$

ρ_p Nanoparticle mass density $\left(kg\ m^{-3}\right)$

σ Electrical conductivity of the fluid

τ Parameter defined by ratio between the effective heat capacity of the nanoparticle material and heat capacity of the fluid. $\tau = (\rho c)_p / (\rho c)_f$

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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MHD Stagnation Point Flow of Micropolar Fluid over a Stretching/Shrinking Sheet

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ARTICLE INFO	ABSTRACT
	In this article, the stagnation point flow of a micropolar fluid on a stretching/shrinking sheet has been discussed subject to the assumption of velocity slip. Similarity transformation is used to transform the modelled Partial Differential Equations (PDEs) into a system of Ordinary Differential Equations (ODEs). The numerical results have been found by the shooting technique along with Adams Moulton method of order four. The obtained numerical results are compared with the help of Fortran Language program and compared with the earlier published results and excellent validation of the present numerical results has been achieved for the local Nusselt number. Finally, the numerical results are presented with discussion of the effects of different physical parameters.

1. Introduction

Stagnation point refers to the location in the flow field when the fluid velocity is zero. In the subject of fluid dynamics, the study of viscous, incompressible fluid passing through a permeable plate or sheet is crucial. Because of its wide range of applications in the manufacturing sectors, research on the stagnation point flow of an incompressible fluid across a permeable sheet has gained prominence in recent decades.

Some of the most common uses include fan-cooled electrical devices, atomic receptacles cooling for the length of an emergency power outage, solar receivers, and so on. Hiemenz [15] was the first to examine two-dimensional (2D) stagnation point flow, while Eckert [11] expanded this problem by including the energy equation to obtain an accurate answer. As a result, Mahapatra and Gupta [14], Ishak *et al.,* [2], and Hayat *et al.,* [29] investigated the effects of heat transmission in stagnation point across a permeable plate.

The effect of slip condition gives an interesting result for different fluids. Sharma *et al.,* [27] investigated the slip effect of the heat transfer due to stretching sheet on a CuO water nanofluid. A

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new model effect of second order slip velocity was introduced by Wu [34]. Wang *et al.,* [6] extended the article of Wu [34] by considering the slip effect of stagnation point flow on a heated vertical plate. Fang *et al.,* [8] investigated the second order velocity slip effect on the viscous flow due to a stretching sheet. Nandeppanaver *et al.,* [19] discussed the heat transfer and second order slip flow due to a stretching sheet. Deissler [7], Rosca and Pop [22] and Turkyilmazoglu [32] investigated the second order velocity slip effect, under different physical conditions.

Many researchers found interest in the study of micropolar fluid for the different geometries. Erigen [12] was the first one who investigated micropolar fluid. Ariman *et al.,* [30] theoretically investigated micropolar fluids and their applications. Ishak *et al.,* [1] discussed the stagnation point flow of a micropolar fluid in a two-dimensional boundary layer flow of mixed convection on a stretching sheet. Bhargava *et al.,* [24] numerically investigated the solutions of micro-polar transport due to a non-linear stretching sheet. Rees and Pop [23] theoretically discussed free convection from a vertical at plate in a micropolar fluid. Nazar *et al.,* [25]. Sajid *et al.,* [28] analyzed the stretching flow with a general slip consition.

System involving chemical reactions are completed. Batcha Srisailam *et al.,* [5] analyzed the effect of viscous dissipation and chemical reaction on the flow of MHD nanofluid over a stretching sheet. Lim Yeou Jiann *et al.,* [18], the effects of Wu's velocity slip and Smoluchowski's temperature slip are taken into consideration. Thirupathi *et al.,* [31] presented a numerical investigation for the magnetohydrodynamics (MHD) stagnation point Casson nanofluid flow towards stretching surface with velocity slip and convective boundary condition. Abu Bakar, Shahirah *et al.,* [3], investigated the mixed convection boundary layer flow over a permeable surface embedded in a porous medium, filled with a nanofluid and subjected to thermal radiation, magnetohydrodynamics (MHD) and internal heat generation. E. N. Maral *et al.,* [10] studied on peristaltic transport of menthol electrolytes altered utilizing an external electric field which contributes to the creation of a net surface charge attracting counter ions and repels co ions from the menthol based nanofluid.

Recently Noreen Sher Akbar *et al.,* [21] focused on the viscous flow of cu-water/Methanol suspended nanofluids towards a 3D stretching sheet. Faisal Z. Duraihem *et al.,* [13] analysed the impact of thermal stratification and medium porosity on gravity-coerced transport of hybrid carbon nanotubes. E.N. Maraj *et al.,* [9] study on oscillatory pressure-driven MHD flow of a hybrid nanofluid in a vertical rotating channel. Khalid Y. Ghailan *et al.,* [17] study of unsteady peristaltic flow across a channel with finite width and porous medium. Javaria Akram *et al.,* [16] investigation emphasizes the fluid flow analysis and the heat transfer characteristics of 10 W40-based titanium dioxide nanofluid subject to electroosmotic forces and the peristaltic propulsion in a curved microchannel. Javaria Akram and Noreen Sher Akbar *et al.,* [4] analysis is conducted for a theoretical examination of the fluid flow characteristics and heat transferred by the nanoparticle enhanced drilling muds flowing through drilling pipes under various physical conditions.

To the best of Authors' knowledge, no information is available on the effect of magnetic parameter on the stagnation point flow of a micro fluid over a stretching/shrinking sheet. The present work is aims to fill the gap in the existing literature. Therefore, in the present paper, we consider the MHD stagnation point flow over a stretching/shrinking sheet placed in a micropolar fluid with second order slip condition. We shall apply Shooting technique along with Adams – Moulton method of order four to solve the similarity equations obtained from the governing boundary layer equations with the help of similarity transformation. The structure of the present paper is as follows: The problem formulation and quantity of physical interest are presented in Section 2. Adams – Moulton method for the proposed problem is presented in Section 3. In Section 4 results and discussion are reported whereas Section 6 is reserved for concluding remarks.

2. Mathematical Modeling

Consider a steady, electrically conducting, two-dimensional stagnation point flow of an incompressible micropolar fluid on a stretching/shrinking sheet with the assumption of slip velocity effect. Assume that $u_e(x) = ax$ be the free stream velocity and $u_w(x) = bx$ be the stretching/shrinking velocity respectively, where a and b are some real constants. The flow configuration and axes system are depicted in Figure 1. The length of the sheet is taken along the $x-$axis whereas $y-$axis taken normal to the sheet.
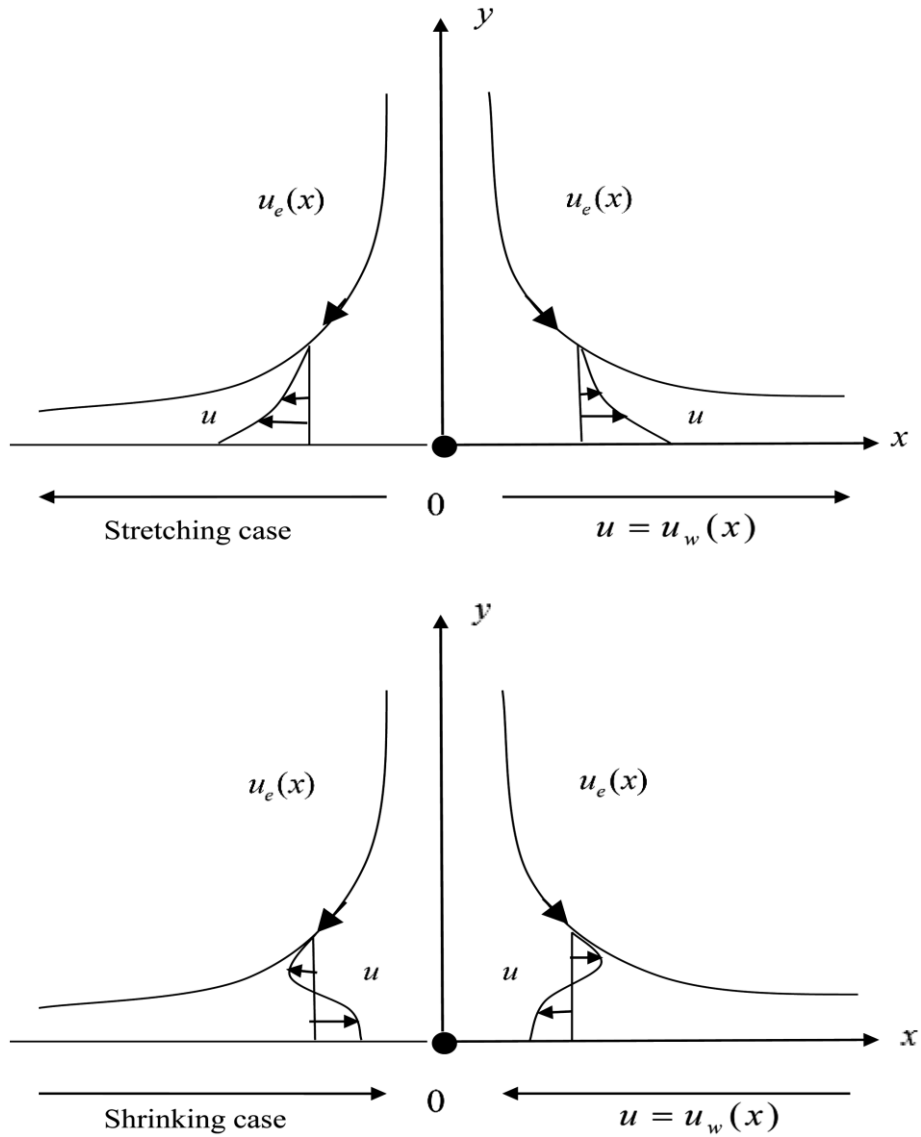
Fig. 1. Geometry of the problem

For stretching sheet $b > 0$ and for shrinking sheet $b < 0$. The mathematical model of the flow, presented by Sharma *et al.,* [26] is as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0,$$

(1)

$$\frac{\partial u}{\partial x}u + \frac{\partial u}{\partial y}v = u_e \frac{\partial u_e}{\partial x} + \left(\frac{\mu+k}{\rho}\right)\frac{\partial^2 u}{\partial y^2} + \frac{k}{\rho}\frac{\partial N}{\partial y} - \frac{\sigma B_0^2}{\rho}(u-u_e) \tag{2}$$

$$\rho j\left(\frac{\partial N}{\partial x}u + \frac{\partial N}{\partial y}v\right) = \left(\mu + \frac{k}{2}\right)j\frac{\partial^2 N}{\partial y^2} - k\left(2N + \frac{\partial u}{\partial y}\right), \tag{3}$$

Where the velocity components has been represented by u and v respectively. Dynamic viscosity is denoted by μ, microrotation viscosity by k, fluid density by ρ, micro inertia density by j and component of microrotation is denoted by N. The boundary conditions of the above equations are given as [31]

$$\left.\begin{array}{l} v = 0, \quad u = u_w(x) + u_{slip}, \quad N = -n\frac{\partial u}{\partial y} \quad at \quad y = 0, \\ u = u_e(x), \quad N \to 0 \quad as \quad y \to \infty, \end{array}\right\} \tag{4}$$

Where $u_e(x), u_{slip}$ and $u_w(x)$ represent the free steam velocity, slip velocity and stretching /shrinking velocity.

In the boundary conditions $n =$ constant with $0 \le n \le 1$. The boundary condition with $n = 0 =$ no slip condition, which requires that fluid particles closest to the solid boundary stick to it. The boundary condition with $n \ne 0$ (i.e., microrotation is equal to the fluid velocity at the boundary) implies that the neighbourhood of a grid boundary.

The stream function identically satisfies the continuity equation. Mathematically,

$$u = \frac{\partial \psi}{\partial y}, \qquad v = \frac{\partial \psi}{\partial x}. \tag{5}$$

Now, introduce the following similarity variables from [26],

$$\left.\begin{array}{l} \psi = \sqrt{\nu x u_e(x)}f(\eta) = \sqrt{a\nu}xf(\eta), \\ \eta = \sqrt{\frac{u_e(x)}{\nu x}}y = \sqrt{\frac{a}{\nu}}y, \\ N = u_e(x)\sqrt{\frac{u_e(x)}{\nu x}}, \\ h(\eta) = a\sqrt{\frac{a}{\nu}}xh(\eta) \end{array}\right\} \tag{6}$$

Where the stream function is represented by ψ and the kinematic viscosity is represented by ν.

Thus, the dimensionless form of the mathematical model of the present problem is:

$$\left(1-f^{'2}\right)+\left(1+K\right)f^{'''}+ff^{''}+Kh^{'}-M\left(f^{'}-1\right)=0, \tag{7}$$

$$\left(1+\frac{K}{2}\right)h^{''}+fh^{'}=f^{'}h+K\left(2h+f^{''}\right) \tag{8}$$

along with BCs:

$$f(0)=0,f^{'}(0)=\varepsilon+\lambda f^{''}(0)+\delta f^{'''}(0),h(0)=-nf^{''}(0), \tag{9}$$

$$f^{'}(\eta)\to 1,h(\eta)\to 0,\text{ as } \eta\to\infty, \tag{10}$$

In the above equations, the micropolar parameter by $K=\dfrac{k}{\mu}=\dfrac{k}{\nu\rho}$ the stretching/shrinking rate has been represented by $\varepsilon=\dfrac{b}{a}$ the first order slip represented by $\lambda=A\sqrt{\dfrac{a}{\nu}}$ and the second order slip by $\delta=B\dfrac{a}{\nu}$ where A and B have the following formulations [7]

$$\left.\begin{aligned}A&=\frac{2}{3}\left(\frac{3-\alpha l^{3}}{\alpha}-\frac{3}{2}\frac{1-l^{2}}{K_{n}}\right)\lambda,\\B&=-\frac{1}{4}\left[l^{4}+\frac{2}{K_{n}^{2}}\left(1+l^{2}\right)\right]\lambda^{2}.\end{aligned}\right\} \tag{11}$$

3. Solution Methodology

The numerical solution of the mathematical model in the form of non-linear differential equations Eq. (7) – Eq. (8) along with the boundary conditions Eq. (9) – Eq. (10) was reported by Sharma *et al.,* [26]. They opted for the finite-difference method for the numerical solution of the above model. In the present section, shooting technique with Adams Moulton method has been proposed to reproduce the same solution. The Adams Moulton method of order four and the Newton's method for solving the non-linear algebraic equations, are the main components of the shooting method. Let us re-write Eq. (7) – Eq. (8) as:

$$f^{'''}=-\frac{1}{\left(1+K\right)}\left[ff^{''}+\left(1-f^{'2}\right)+Kh^{'}+M\left(f^{'}-1\right)\right], \tag{12}$$

$$h^{''}=\frac{2}{(2+K)}\left[fh^{'}-f^{'}h-K\left(2h+f^{''}\right)\right]. \tag{13}$$

Use the notations to construct a system of first order ODEs:
$$f=y_{1},f^{'}=y_{2},f^{''}=y_{3},h=y_{4},h^{'}=y_{5} \tag{14}$$

By using the notations Eq. (14), we have the following IVP:

$$
\left.
\begin{array}{ll}
y_1' = y_2, & y_1(0) = 0, \\[4pt]
y_2' = y_3, & y_2(0) = s, \\[4pt]
y_3' = -\dfrac{1}{(1+K)}\left[y_1 y_3 + \left(1 - y_2^2\right) + K y_5 + M\left(y_2 - 1\right) \right], & \\[8pt]
& y_3(0) = \dfrac{1}{\lambda}\left[s - \varepsilon + \delta\left(\dfrac{1}{1+K}\right)\left(\left[\left(1 - s^2\right) + Kt\right]\right) \right], \\[8pt]
y_4' = y_5, & y_4(0) = -\dfrac{n}{\lambda}\left[s - \varepsilon + \delta\left(\dfrac{1}{1+K}\right)\left(\left[\left(1 - s^2\right) + Kt\right]\right) \right], \\[8pt]
y_5' = \dfrac{2}{(2+K)}\left[-y_1 y_5 + y_2 y_4 + K(2y_4 + y_3) \right], & y_5(0) = t.
\end{array}
\right\}
\tag{15}
$$

In order to get the approximate numerical results, the problem's domain is considered to be bounded i.e., $[0, \eta_\infty]$, where η_∞ is chosen to be an appropriate finite positive real number so that the variation in the result for $\eta > \eta_\infty$ is ignorable. In Eq. (15), the missing initial conditions s and t are to be chosen such that.

$$
y_2\left(\eta_\infty, s, t\right) - 1 = 0,\ y_4\left(\eta_\infty, s, t\right) = 0.
\tag{16}
$$

To start the iterative process, choose $s = s_0$, and $t = t_0$. To the values of s, t Newton's iterative scheme has been used.

$$
\begin{pmatrix} s_{n+1} \\ t_{n+1} \end{pmatrix}
= \begin{pmatrix} s_n \\ t_n \end{pmatrix}
- \begin{pmatrix} \dfrac{\partial y_2}{\partial s} & \dfrac{\partial y_2}{\partial t} \\[8pt] \dfrac{\partial y_4}{\partial s} & \dfrac{\partial y_4}{\partial s} \end{pmatrix}_{(s_n, t_n)}^{-1}
\begin{pmatrix} y_2\left(\left(\eta_\infty, s_n, t_n\right) - 1\right) \\[6pt] y_4\left(\left(\eta_\infty, s_n, t_n\right)\right) \end{pmatrix}
\tag{17}
$$

To implement the Newton's scheme, consider the following notations:

$$
\frac{\partial y_1}{\partial s} = y_6, \frac{\partial y_2}{\partial s} = y_7, \ldots\ldots\ldots\ldots\ldots\ldots \frac{\partial y_5}{\partial s} = y_{10},
$$

$$
\frac{\partial y_1}{\partial t} = y_{11}, \frac{\partial y_2}{\partial t} = y_{12}, \ldots\ldots\ldots\ldots\ldots\ldots \frac{\partial y_5}{\partial t} = y_{15}.
$$

Differentiating Eq. (15), first w.r.t. s and then w.r.t. t, we get the following fifteen first order ODEs along with the associated initial conditions.

$$y_6' = y_7, \qquad\qquad\qquad\qquad y_6(0) = 0,$$

$$y_7' = y_8, \qquad\qquad\qquad\qquad y_7(0) = 1,$$

$$y_8^1 = -\frac{1}{(1+K)}\left[y_6 y_3 + y_1 y_8 - 2y_2 y_7 + K y_{10} + M\, y_9\right], \quad y_8(0) = \frac{1}{\lambda}\left[1 - \left(\frac{2\delta s}{1+K}\right)\right],$$

$$y_9' = y_{10}, \qquad\qquad\qquad\qquad y_9(0) = -\frac{n}{\lambda}\left[1 - \frac{2\delta s}{1+K}\right],$$

$$y_{10}^1 = \frac{2}{(2+K)}\left[-y_6 y_5 + y_7 y_4 + y_2 y_9 - y_1 y_{10} + K(2y_9 + y_8)\right], \quad y_{10}(0) = 0,$$

$$y_{11}' = y_{12}, \qquad\qquad\qquad\qquad y_{11}(0) = 0,$$

$$y_{12}' = y_{13}, \qquad\qquad\qquad\qquad y_{12}(0) = 0,$$

$$y_{13}^1 = -\frac{1}{(1+K)}\left[y_{11} y_{13} + y_1 y_{13} - 2y_2 y_{12} + K y_{15} + M\, y_{11}\right], \quad y_{13}(0) = \frac{1}{\lambda}\left[\left(\frac{2\delta s}{1+K}\right)\right],$$

$$y_{14}' = y_{15}, \qquad\qquad\qquad\qquad y_{14}(0) = -\frac{n}{\lambda}\left[\frac{2\delta s}{1+K}\right],$$

$$y_{15}^1 = \frac{2}{(2+K)}\left[-y_{11} y_5 + y_{12} y_4 + y_2 y_{14} - y_1 y_{15} + K(2y_{14} + y_{13})\right], \quad y_{15}(0) = 1$$

$$(18)$$

Next, the IVP in the form of fifteen first order ODEs given in Eq. (15) and Eq. (18) is solved by the fourth order Adams Moulton method and the Newton's method. If for a sufficiently small ε^*,

$$\max\left\{\left|y_2\left(\eta_\infty, s_n, t_n\right) - 1\right|, \left|y_4\left(\eta_\infty, s_n, t_n\right) - 1\right|\right\} > \varepsilon^* \tag{19}$$

The guessed values of s and t are updated by the Newton's iterative scheme:

$$\begin{pmatrix} s_{n+1} \\ t_{n+1} \end{pmatrix} = \begin{pmatrix} s_n \\ t_n \end{pmatrix} - \begin{pmatrix} y_7 & y_{12} \\ y_9 & y_{14} \end{pmatrix}^{-1}_{(s_n, t_n)} \begin{pmatrix} y_2\left(\left(\eta_\infty, s_n, t_n\right) - 1\right) \\ y_4\left(\left(\eta_\infty, s_n, t_n\right)\right) \end{pmatrix} \tag{20}$$

The iterative process is repeated until the following criteria is met.

$$\max\left\{\left|y_2\left(\eta_\infty, s_n, t_n\right) - 1\right|, \left|y_4\left(\eta_\infty, s_n, t_n\right) - 1\right|\right\} < \varepsilon^* \tag{21}$$

4. Results and Discussion

The main objective of the present section is to study the effect of different physical parameters like K (micro-polar parameter), λ (the first order slip parameter), ε (the stretching/shrinking rate), δ (the second order slip parameter) on the velocity and micro-rotation profiles. The present results have been compared with the previous results of Wang [33] and Bachok *et al.,* [20] for different values of the stretching/shrinking rate ε in Table 1 which are in good agreement. Wang [33] and Bachok *et al.,* [20] have discussed the stagnation point flow towards a stretching/shrinking sheet.

Table 1
Comparison of $f''(0)$ for different values of ε when $\lambda = 0, \delta = 0, K = 0$, and $n = 0.5$

Values of ε	Wang [33]	Bachok *et al.,* [20]	[26]	Current results
2.0	-1.88731	-1.8873066	-1.88730667	-1.88730627
1.0	0	0	0	0
0.5	0.713300	0.7132949	0.71329496	0.71525570
0.0	1.232588	1.2325877	1.23258765	1.23257700
-0.25	1.402240	1.4022408	1.40224081	1.40224872
-0.5	1.495670	1.4956698	1.49566977	1.49566265
-1.0	1.328820	1.3288170	1.32881688	1.32881259
-1.2	0.554300	0.9324730	0.93247336	0.93247167
-1.2465	--	0.5842956	0.58428274	0.58428643

The impact of the first order slip λ on the velocity profile is presented in Figure 2. By increasing the values of the λ, the velocity profile is increased. Physically, when a slip occurs, the velocity of flow near the sheet is no longer equal to the stretching velocity of the sheet.

The variations in the micro-rotation profile for the λ are demonstrated in Figure 3 and 4. An opposite flow behavior is determined with the first and second solution. The thickness of boundary layer is deceased in the first solution and increases in the second solution.

Figure 5 and Figure 6 demonstrate the impact of the second order slip parameter δ on the velocity profile. Figure 5 indicates that by increasing δ, the velocity profile is increased. Figure 6 represents that by increasing δ, the velocity profile is reduced.

The variations in the microrotation profile for different values of the second order velocity slip δ are demonstrated in Figure 7 and Figure 8. It shows that the microrotation profile is initially increased as δ is increased for the first solution and microrotation profile is decreased as δ is increased for the second solution.

The variations in the velocity profile for micropolar parameter K are demonstrated in Figure 9 and Figure 10. By increasing the values of the micropolar fluid K, the velocity field is reduced in both the first and the second solution. It is evident from Figure 9 and Figure 10 that all curves approach the far field boundary conditions asymptotically.

The variations in the microrotation profile for micropolar parameter K are demonstrated in Figure 11 and Figure 12. From these graphs, it can be observed that increasing the micropolar K, the velocity field is reduced in the lower half of the surface whereas it is enhanced in the upper half. The velocity is going to reduce initially with the mounting values of the micropolar K. The boundary layer thickness is increased in both the first and the second solution.

Figure 13 illustrates the changes in the velocity profile at various magnetic field strengths. As the magnetic field strength increased, the velocity profile increased. This phenomenon is a result of the magnetic field that enhances fluid motion within the boundary layer.

Figure 14 shows the variation in the micro-rotation profile for different estimations of the magnetic field M. By increasing M, the micro-rotation is increased. Thus, the boundary layer thickness is decreased.
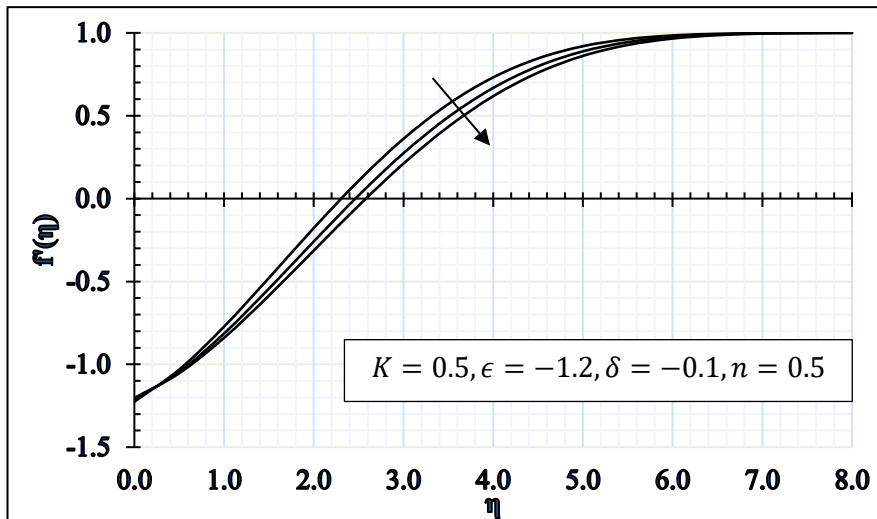
Fig. 2. Impact of $\lambda = 0.05, 0.1, 0.15$ on $f'(\eta)$
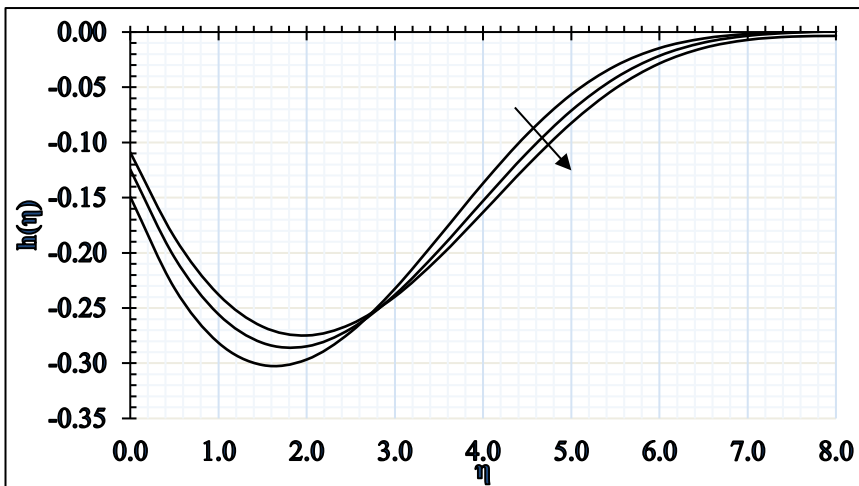
Fig. 3. Impact of $\lambda = 0.05, 0.1, 0.15$ on $h(\eta)$
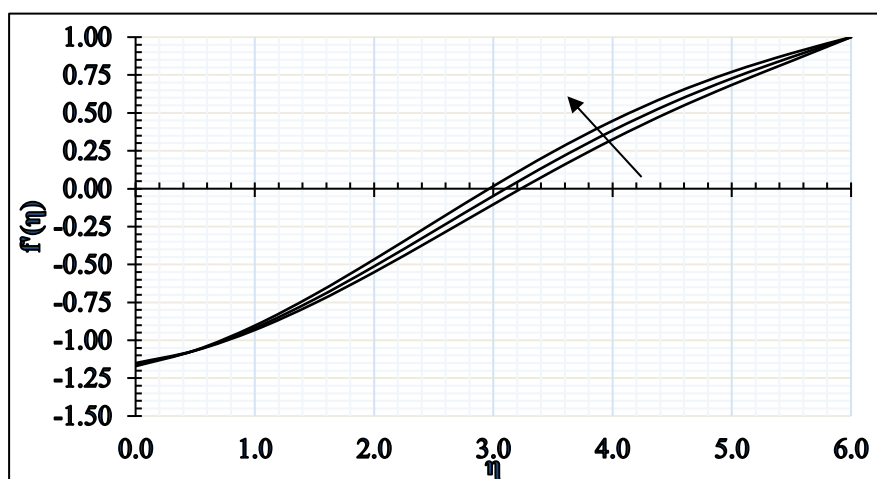
Fig. 4. Impact of $\delta = 0.05, 0.10, 0.15$ on $f'(\eta)$
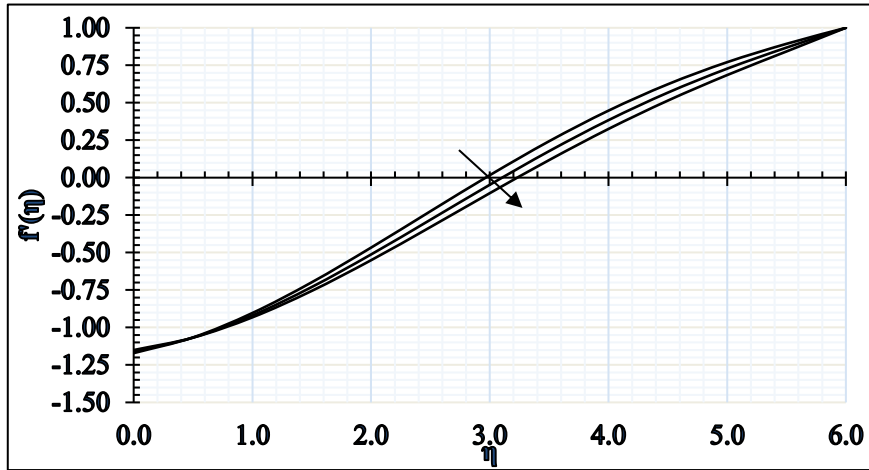
Fig. 5. Impact of $\delta = 0.05, 0.10, 0.15$ on $f'(\eta)$
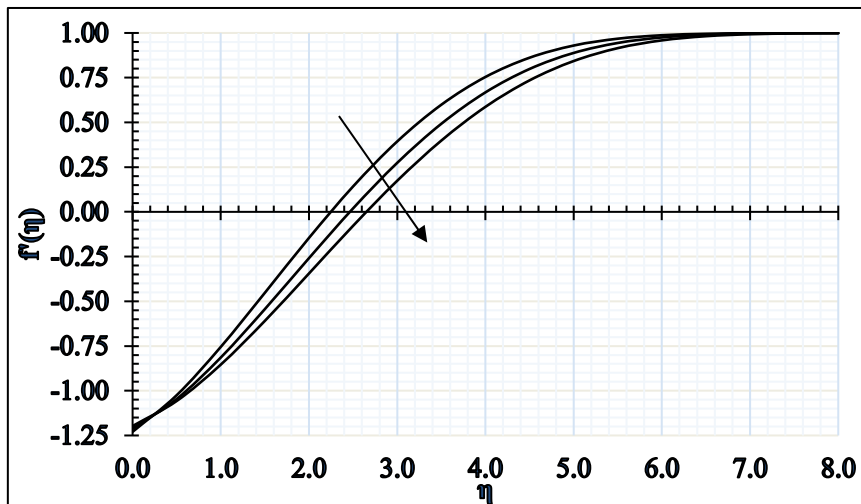
Fig. 6. Impact of $\delta = -0.05, -0.10, -0.15$ on $f'(\eta)$
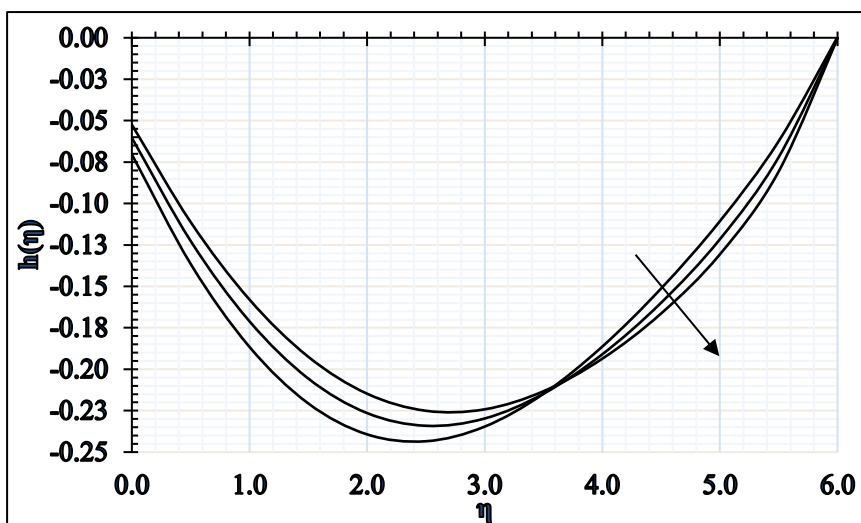
Fig. 7. Impact of $\delta = 0.05, 0.10, 0.15$ on $h(\eta)$
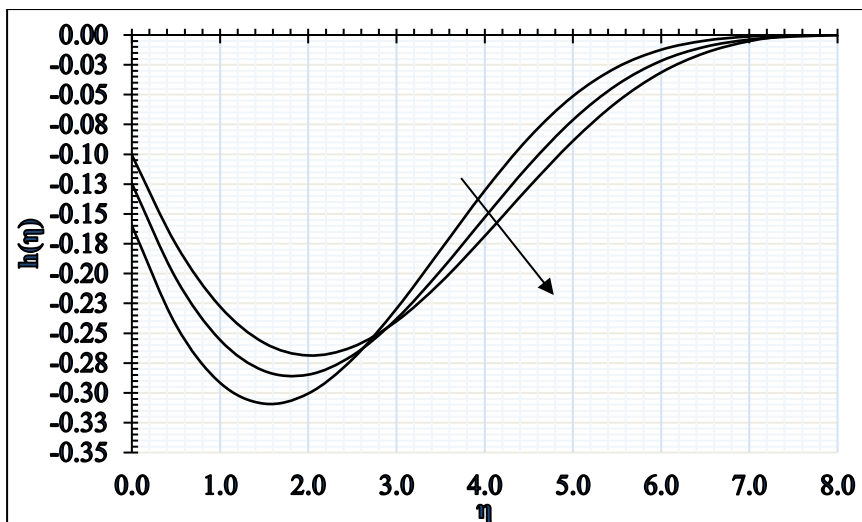
Fig. 8. Impact of $\delta = -0.05, -0.10, -0.15$ on $h(\eta)$
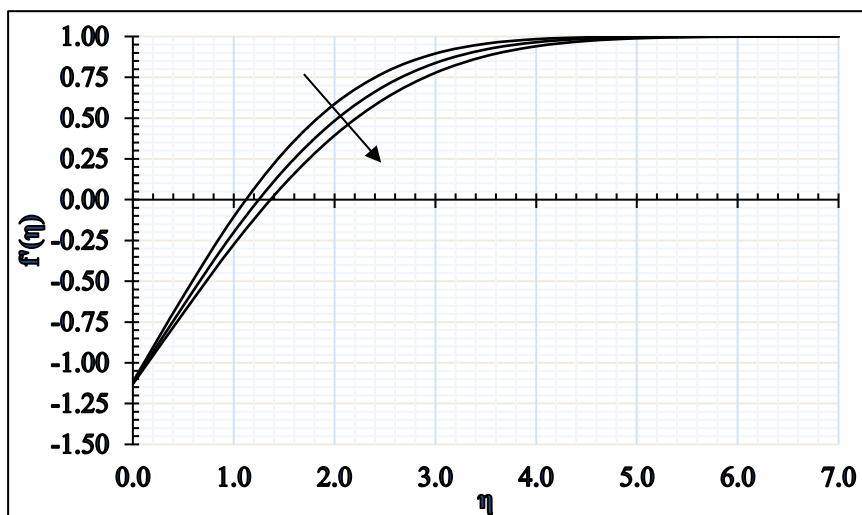
Fig. 9. Impact of $K = 0.05, 0.10, 0.15$ on $f'(\eta)$
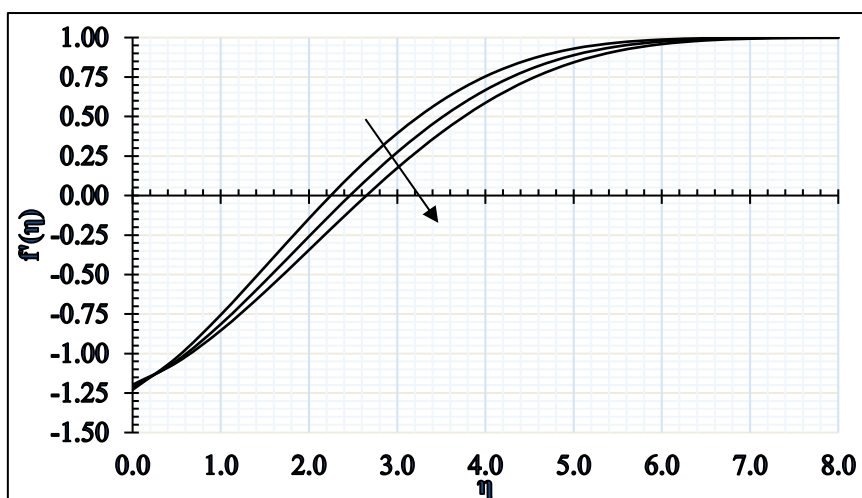
Fig. 10. Impact of $K = -0.05, -0.10, -0.15$ on $f'(\eta)$
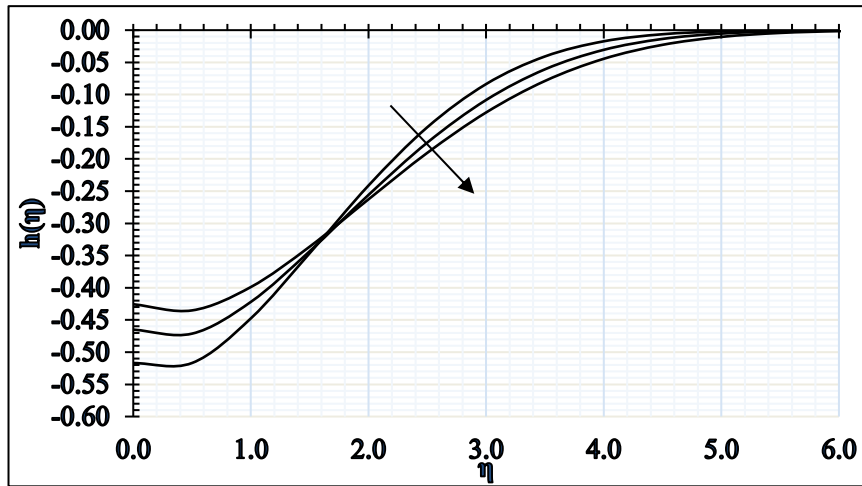
Fig. 11. Impact of $K = 0.05, 0.10, 0.15$ on $h(\eta)$
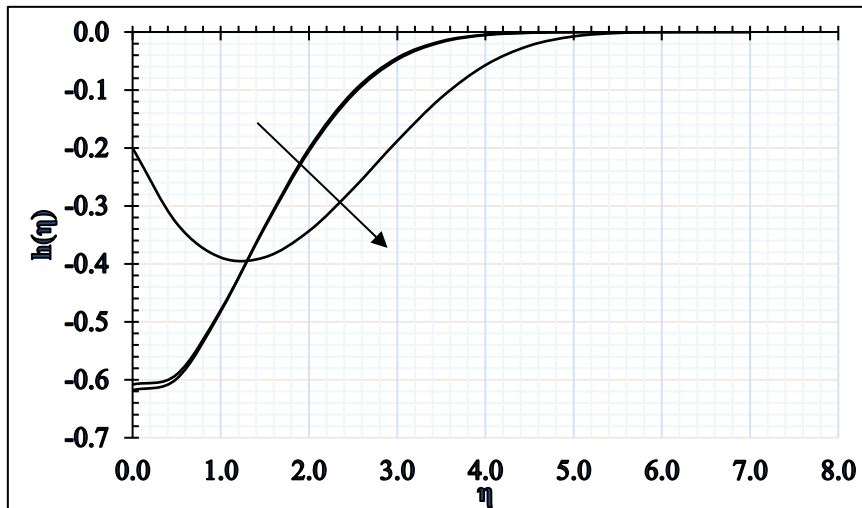
Fig. 12. Impact of $K = -0.05, -0.10, -0.15$ on $h(\eta)$
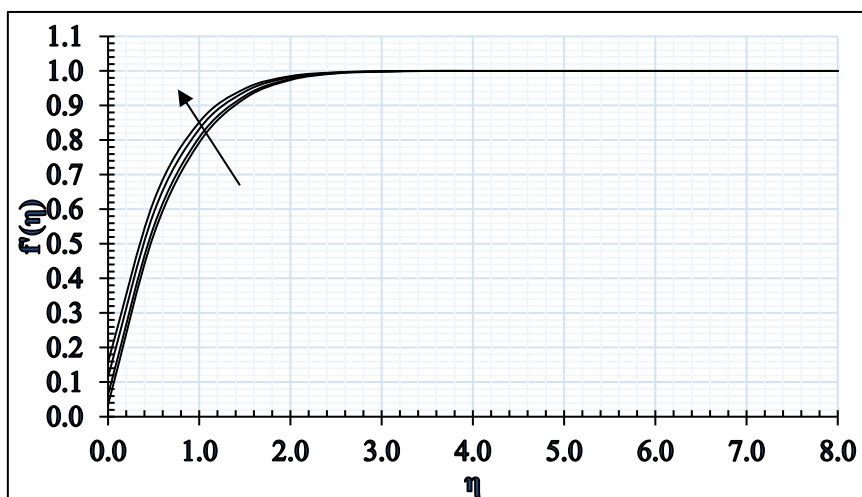
Fig. 13. Impact of $K = 0.05, 0.10, 0.15$ on $f^{'}(\eta)$
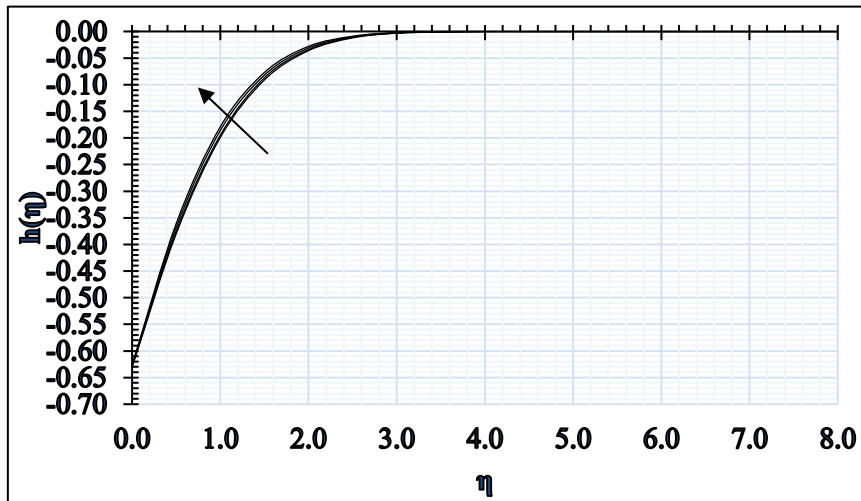
Fig. 14. Impact of $K = 0.05, 0.10, 0.15$ on $h(\eta)$

4. Conclusions

The governing equations for the 2D stagnation point flow of a viscous and incompressible fluid over a stretching/shrinking sheet with second order slip boundary condition and magnetic field were formulated. The resulting partial differential equations were transformed into a set of ordinary differential equations using the similarity transformations.

These equations are solved numerically using Shooting techniques with Adams Moulton method. The conclusions of the study are as follows:

Increasing the suction parameter, the velocity and microrotation profiles are increased. Due to an increase in the shrinking parameter, the velocity and micro-rotation profiles are decreased. Increasing the micropolar parameter, the velocity and micro-rotation profiles are decreased. By increasing magnetic field, the velocity and micro-rotation profiles are increased. This problem may be extended in many directions focusing on the fluid model of Jeffery, Tangent hyperbolic nanofluid.

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The Role of Artificial Intelligence in Reimaging the Customer Experience in Retail Sector – NVIVO Analysis for Customer Journey Mapping

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Abstract: The term "Artificial Intelligence" (AI) is frequently used to describe intelligent software, devices, or systems. Its use can improve the intelligence of goods, services, and solutions, making it a field of research that is fast expanding and will have a big impact on the market. Retailers use AI to analyse massive amounts of data produced through sales, online surfing, social media, mobile usage, and consumer satisfaction, and it has become an essential component of the retail business. Retailers are investing in a number of AI solutions due to the exponential growth of corporate data. Spending on AI reached $6 billion by 2022, or around $18 per person in the US. The demand and supply sides of retailing are impacted by AI. On the demand side, it assists and guides retailers understand and anticipate customer needs, enhance customer lifetime value, and improve decision-making. Whereas AI optimizes inventory management and logistics on the supply side, to make supply chains more efficient. AI also changes the relationship between shoppers and retailers by assisting consumers in their decision-making. This paper provides a framework for understanding AI, highlighting its applications in different aspects of retailing. It supports and orients the demand side.

Keywords: Artificial Intelligence, Customer Experience, Retailing, NVIVO Analysis, Decision Making.

1. Introduction

Artificial intelligence (AI) is a concept that has captivated our attention for good reason. Think about a situation in which you could simply instruct your smartphone or wearable to move money from your savings account to your checking account in order to pay a bill, all while getting personalized financial advice. This is just one instance of how AI is becoming more and more significant in our lives. Automation can be enhanced with AI, giving machines the ability to learn and decide for themselves while self-correcting over time. Through customization and interactivity, it may help businesses adjust to "servitization" and draw customers closer to online sellers. Additionally, AI has the power to generate market and consumer insights, automate company operations, and enhance customer experiences. In order to maximize revenue per client, this technology is being used more and more in pricing, risk assessment, marketing, and contact Centre response management. AI can be considered as a component of a bigger framework that also incorporates big data and machine learning in order to comprehend it and its function in retailing. Retailers like Amazon are the industry leaders in AI, continually gathering, curating, and analyzing data to make crucial decisions that improve customer experiences and data acquisition. Figure 1 illustrates how AI is constantly used to collect data, analyze it, and then help make decisions.

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The Impact Of Digital Marketing On Herbal Drug Consumers
A Review Study

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Purchasing medications online has become a popular trend among patients and consumers. With the rise in demand for online prescription purchases, the number of online pharmacies has also grown. The annual Indian pharmaceutical market is valued at approximately Rs 79,000 crore, with a growth rate of around 20%. Pharmaceutical companies are highly competitive in marketing their products. The revenue generated from online sales of healthcare products in India reached INR 5,075.9 million in FY 2015, up from INR 771.0 million in FY 2012, reflecting a compound annual growth rate (CAGR) of 87.4% during the period from FY 2012 to FY 2015.

Online Marketing and Pharmaceutical Industry

With the advent of social media before meeting a doctor, the patient researches everything about the disease its symptoms, diagnosis, possible cures etc, and has already interacted with other patients. Patients are also more and more aware of their rights and have high expectations from the physicians and the drug companies alike.

Pharmaceutical companies have shifted to online DTC advertisement of prescription drugs through interactive internet platforms like face book, twitter, google plus and linked. Social networking provides a great opportunity for the pharmaceutical industry to come near to their customer and reach out to new and broader customer base.. It can be said that social media acts as a direct, interactive and engaging medium (Bhagat and Dutta, 2012).

Myers, D. S. (2012) found that companies across product categories are working to learn the nuances of social media as it continues to grow in popularity and wide spread adoption. Pharmaceutical companies are no different, except that they must

also adapt government regulation and industry standards to the new medium, making the topic important for pharmaceutical companies, consumers, and policy makers.

The social media afford a great opportunity for the pharmaceutical industry to reach world wide audience. It allows companies to traverse boundaries. The huge growth in the social networking will be virtual in the developing countries like India after an widespread coverage in the developed markets. Social media could be a very strong and effective medium for the pharmaceutical industry for communicating their values and strategies to their customers. Chatterjee(2012).

Previous research studies report that 50 percent of online pharmacies operate without license, 33 percent do not have policies in place to protect their customers and many do not provide a contact address and phone number and hide from law enforcement (Silverman and Perlstein,2009). According to the World Health Organization (2009), medicines purchased over the internet from websites that conceal their physical address are counterfeit in more than half of the cases.

Richards (2008) in an overview found that most of the doctors think that its testing to remain educated about medicines and prescriptions. To remain educated they survey, analyze, and coordinate data from numerous sources. Most doctors say that data from pharmaceutical and biotech look into organizations is helpful to them, and they acknowledge visits from organization agents and the data and assets they give. Although most doctors welcome this data, they don't utilize it in separation" Patients who see a commercial and perceive their own side effects or hazard variables may then contact their doctor to talk about their treatment alternatives, hence sharing in their medicinal services administration (West, 2012).

Online pharmaceutical stores have limited capability to sign trust due to their incapacity to convey longevity in the marketplace. Unlike physical stores that require significant investments into property, personnel and inventory, online stores enjoy low entry cost and are relatively easy and inexpensive to maintain.(Grewal,et.al2004).The minimal expenses required for entering and exiting online marketplaces create doubts for consumers as they are uncertain if the online retailer will stay in business for a long time (Jarvenpaa,2010). The

anonymity provided to the seller by the very nature of the internet creates ambiguity and does nothing to alleviate the buyer's apprehension. The true identity of the seller can be hidden by domain names, fake addresses, and distorted information—the inability of the buyer to distinguish between true and false increases consumer uncertainty [7].

Gupta and Udupa (2011) study recommends that mindfulness and acknowledgment of the idea of web-based social networking promoting is high among both the physicians and the patients. Among physicians it is emphatically and altogether connected with youthful age and having a postgraduate degree after MBBS. Among the patients, a high extent take self-drug in light of reference to the web, most regular diseases for utilization of self-medicine being hurts, respiratory ailments and gastrointestinal ailments .

Mack (2010) said that doctors today are probably going to get medicate data from an different sources and very regularly these sources are access to by means of the Internet. Gadgets, for example, iPhone and soon iPad—will make it much more helpful for doctors and patients to get online substance.

More than seventy five percent of doctors trust that the Internet has influenced clinical to hone 'simpler', as indicated by a 2009 overview.(Parekh and Rojowsky,2009).With the expanding technological means for social occasion diagnostic information and treatment alternatives, more decisions must be considered. This can leave less time for clinical choices, which regularly should be made inside a matter of minutes.

The Online medicinal services products advertise has displayed an astounding development amid the traverse of most recent five years on the grounds of extension in item extend and also surge in online commercial centers. In accordance with the Business incomes, the normal request estimate has likewise broadly improved which has been enlisted at INR 1,762.0 amid FY'2015. Besides Direct-To Consumer Advertising (DTCA) and other traditional marketing practices, pharmaceutical companies generate revenues through different activities which are complex in nature.

With one click access to tens of thousands of online pharmacies and unlimited products to choose from, it is crucial for consumers to investigate whether the convenience outweighs the inherent risks of purchasing medicines online. However, confirming the veracity of an online pharmacy is also conflated by the use of falsified seals and fraudulent licensure information and accreditations, which may lure consumers into a false sense of security.(Liang BA Mackey,2003) Searching for safety: addressing search engine, website, and provider accountability for illicit online drug sales

A growing number of online pharmacies have been established worldwide. The online promotion of prescription drugs directly to consumers has turned into an undeniably well known technique for tranquilize promoting in the vast majority of the developing nations. Traditionally, pharmaceutical companies' promotional efforts were directed almost exclusively to doctors and healthcare providers..(Campbel).

Primary motivating factors that lead consumers to shop with online pharmacies include perceived lower cost (although some studies have identified higher prices from online pharmacies for certain classes of drugs and additional costs not associated with the drug's price), convenience (i.e. 24/7 website availability), greater patient autonomy and perceived privacy from shopping online (Orizio G.Merla A Schulz,PJ, et al.,2013).

The Quality of online pharmacies and websites selling prescription drugs: a systematic review complicating online health seeking and purchasing behavior are studies reporting low health literacy among potential consumers even when there are clear characteristics of patient safety risks present.(Mackey and Liang 2013)

With one click access to tens of thousands of online pharmacies and unlimited products to choose from, it is crucial for consumers to investigate whether the convenience outweighs the inherent risks of purchasing medicines online. However, confirming the veracity of an online pharmacy is also conflated by the use of falsified seals and fraudulent licensure information and accreditations, which may lure consumers into a false sense of security(Liang and Mackey,2003)

Searching for safety: addressing search engine, website, and provider accountability for illicit online drug sales.

An observational study in Germany found that e-patients generally do not read disclaimers, disclosures or 'about us' sections on health sites (Eysenbach and Köhler, 2002).

To address the problem of online pharmacies in foreign countries, the FDA has begun to send "cyber letters" to foreign pharmacies that it suspects are selling illegal prescription drugs to Americans.47 The cyber letter is only a warning letter that puts the pharmacy on notice that it may be violating U.S. laws, and that U.S. customs officers may refuse entry of packages delivered from their site into the country (Sara and Zeman,2010).

The greater part of the pharmaceutical and healthcare companies in India - multi-national and domestic - have a placeholder presence on digital platforms and are neglecting to effectively draw in with their partners, the ' India Digital Health Report 2017'

Nowadays due to increase in literacy and health consciousness of people, pharmaceutical companies feel the need to approach a large category of people to inform them about their products and to earn more profits. In the Indian population, advertisers can reach their audiences through television, radio, print media, outdoor advertising, sales promotion and the Internet (Parakh et al 2017)

As technology changes, the advertising medium is also taking new dimensions. Patients increasingly are turning to digital media to aware more about their diseases and treatments since much of the information they receive from traditional sources is "difficult to understand and interpret." (Sherri Matis-Mitchell 2014) .

All of these pharmaceutical companies today have a face book page, twitter channel, and supported web journals. Pfizer has the most powerful web based life site, including connections to YouTube, Face book, and Twitter, and Slide Share, LinkedIn, Flickr, and blog assets (Liang and Mackey, 2016)
Three out of five e-patients in a 2006 survey revealed that health information online affects their health care decisions.(Pew Internet & American Life Project,

2006) . Most important, online information can directly influence which drugs patients request from the doctors (*Cline and Haynes 2017).*

Beyond overestimating source credibility, users are vulnerable to online pharmaceutical misinformation when they are unaware of whether the source of health information is a drug company or a more neutral party (e.g.a health information website).Given the Internet's speed and ease of use, web users are also often unaware of drug misinformation because they seldom take time to verify the reliability of the sources they access (Eysenbach and Köhler 2012).

Despite the fact that web has turned into a vital medium for prescription drug advertisements it is unregulated, which could imply that the data accessible can be inconsistent if not acquired from genuine source. Another problem is the advanced gap in which accomplished and prosperous individuals from society will probably utilize the web for health reason than their less-instructed partners (Korp, 2015).

Pharmaceutical organizations utilize electronic DTCA on interactive platform (e-DTCA 2.0) to market themselves and their best offering drugs. e-DTCA 2.0 is additionally utilized by illegal online medication merchants. Controllers worldwide must consider the present e-DTCA 2.0 nearness when endeavoring to achieve arrangement and security objectives. People view on an average 30 hours every year (Liang and Mackey, 2011).

Online pharmaceutical marketing and drug consumption:

online retailing is the quickest developing appropriation channel for OTC customer health products around the world. Buyers are progressively pushing toward the utilization of advanced stages for comfort and speed in conveyance, which fit costumers busy lives. online media has revolutionized the sale of medicines so that consumers can self-select and buy medicines, often delivered across national and state boundaries, without face-to-face interaction (Bessel et al., 2003). Many certified e-drug stores are at present accessible on the Internet yet a vital number of illicit medication dealers are additionally working on the web. E-drug stores look engaging purchasers since they spare treks to specialists, never have long holds up in line and frequently offer diminished costs.

Moreover, some offer private e-mail additionally to discuss medications with a druggist, tools for checking interactions with other drugs, e-mail refill reminders and tools for tracking and viewing past orders. Some sites such as Drugstore.com (D-Store, 2005) are associated with a pharmacy chain (Rite Aid (RAC, 2005) in this case for giving customers the option of having the prescription filled at the local pharmacy where they can pick it up faster and safer.

Some medication companies are likewise creating developing health management tools for versatile applications, which are accessible in online markets, for example, the Apple iTunes Store and the Android Market. Although numerous early advanced cell applications concentrated essentially on diabetes administration devices, there has presently been fast venture into other sickness classifications (Pharmaceutical Industry Rapidly Expanding Partnerships with New Entrants in Health Care Space(Ernst and Young 2011).

There are some potential benefits of online DTCA. Communication of patient safety risks and public health information, coordination with existing regulatory tools such as FDA risk evaluation and mitigation strategies and Med Watch, and integration of reliable information into online searches can benefit patients (Kuehn BM). FDA weighs limits for online ads.(JAMA,2010).

Although people can get information directly from pharmaceutical companies' sites, they can also search for information about particular drugs within popular social media sites. In particular, Face book, Twitter, and YouTube are 3 of the most common social media platforms (Duggan,2014).

Though internet has become an important medium for prescription drug advertisement, it is unregulated, which could mean that the information available can be unreliable if not obtained from authentic source. Another concern is the digital divide in which well-educated and affluent members of society are more likely to use the internet for health purpose than their less-educated counterparts (Korp, 2005).

Many successful social media campaigns were found to be in the area of pregnancy, childcare, oncology and geriatrics(Supriti Agrawal & Navjot Kaur, 2015). Internet sites claiming to sell authentic Viagra, shipped counterfeit medication 77% of the time; counterfeits usually came from non-U.S. addresses and had 30%-50% of the labeled API (active pharmaceutical ingredients) claim. Caution is warranted, when purchasing Viagra via the Internet (Campbell, N, 2012). The online health information & DTC Campaigns, greatly influenced the health discourse of the consumers.

Buying from a website that is not a registered pharmacy offers no opportunity for a healthcare professional to assess whether the medicine is safe and appropriate for the individual concerned, or to advise on how the medication should be taken. The information about medicines available on some websites can be incomplete, even where it might be factually accurate (Clauson ,Polen, et.a.,2008).

The internet additionally encourages access to anti-bionics without a prescription. It is realized that self solution utilizing anti-antibiotics happens in all nations, however as of now there is restricted confirmation with regards to the degree that antibiotics are really obtained over the web, without prescription, for this purpose(261).

Another study by Huh and colleagues on the trust of on-line advertisements on prescription drugs found that majority of respondents do not trust the information provided on-line on prescription drugs (Huh et al., 2005).

In developed countries, online pharmacies supply so-called 'lifestyle drugs', such as for weight loss, hair loss or erectile dysfunction. There is likely to be less demand for therapeutic medication in countries with "high social security coverage" (such as France) given that the price of the relevant pharmaceutical may actually be higher than in domestic pharmacies(Mahé,Saiag,Aegerter and Beauchet(2009). Electronic health (e-health) empowers patients, fosters clinician patient relationships and promotes evidence based medicine (Liang and Mackey, 2011).

Weckmann (2012) conducted a content analysis of websites for antidepressants. They found that most websites were easily accessible through search engines and contained information useful to educating consumers about medical symptoms. They also reported few comparisons between drug efficacy and adverse effects, however, making it difficult for consumers to make rational choices about drug selection. It is worth not to ignore the confusing effect of some e-DTCA, a study conducted by Hyla et al. to measure the impact of e-DTCA on patients' behaviors found that more than one quarter of their respondents were confused from the advertisements. In addition many of them stopped taking their medications due to considerable side effects mentioned in the advertisement (Hyla et al., 2009).

Moore and Newton (1998) argued that the Web has features of both print and broadcast media and its interactivity makes it very different from any other media. Unlike other traditional media, website visitors are not passively ''exposed'' to content because, on the web, information is not ''pushed'' but ''pulled'' by viewers. Where information is located and how it is displayed as well as how viewers browse the website, therefore, can be more important than the information itself. Graber and. Macias and Lewis (2003) analyzed the content of DTC prescription drug websites and found that most provided consumers with rich information and great educational value. From the results, the authors inferred that, in general, pharmaceutical companies were conforming to FDA requirements.

Thus, the role of an individual prescription drug website has increased in importance. More than 25 million consumers have visited a pharmaceutical product website in the past 12 months). If a website does not provide consumers with balanced information on benefits and risks, consumers may be misled(Manhattan Research, 2014).

The developments in the pharmaceutical segment offer new ways for individuals to online purchases of heath products and medicines. This industry market estimates to be generating3,000-4,000 orders on a daily basis (Supriti,2015).Though online medicines look like a promising trend today the business is challenged by regulatory issues. There are no dedicated online pharmacy laws in India as on date.

Traditionally, pharmaceutical companies controlled all the information regarding their products and they would also control release of this information. But Modern pharmaceutical industry goes beyond the traditional business of marketing and selling of medicines. The Direct-to-Consumer Advertising (e-DTCA) of pharmaceutical firms has been characterized as an endeavor of pharmaceutical organizations to publicize or promote data in regards to a physician recommended medicate specifically to patients. The DTCA can be performed through different channels including, television broadcast, billboards, websites and consumer magazines (Abel et al., 2006). Most of the pharmaceutical companies are very aggressive in marketing and sales of their products. They meet their targets by different other activities along with the Direct-To Consumer Advertising (DTCA) in the market. Besides traditional marketing practices, pharmaceutical companies generate revenues through different other activities, which are complex in nature.

The advent of digital technology has changed the way the information is accessed, processed and used and health information is not an exceptional. The medical community and public started using heavily the Internet for health information. Modern pharmaceutical industry goes beyond the traditional business of marketing and selling of medicines.

The last few decades have seen a dramatic transformation of the consumer's role in health care. Physicians' authority over the prescribing of drugs has been directly challenged by DTC advertising campaigns urging consumers both to self-diagnose and to demand specific medications from their provider (Donohue,2006). Today, consumers especially youth are informed and aware of the medicines being promoted through different sources including internet and social media and are able to take their own health care decisions. They are determent, aware and well informed that they know longer are scared to question the suggestions of the doctors Gupta and Udupa, 2011).

Pharmaceutical companies have shifted to interactive online platforms like Facebook, Twitter, Google plus, company websites etc. Social networking provides a great opportunity for the pharmaceutical industry to reach out to new and broader customer base. The online provides an unique experience to

consumers as it is direct, interactive and engaging medium (Bhagat and Dutta, 2012).

Online pharmacies can be advantageous to customers (eg, convenience, security, free access to data, correlation shopping, and so on) yet can likewise convey with them various inconveniences (eg, absence of significant interaction with doctor and drug specialists, misdiagnosis, wrong utilization of medications, individual information assurance, and so on (*Orizio and Merla 2011*)

In most of the cases consumers don't know that products offered by online pharmacy might not have a similar quality that a retail drug store may offer [Online drug stores: security and administrative considerations.Montoya ID, Jano EInt J Health Serv. 2007; 37(2):279-89.] and regularly it is hard to decide if a site is authentic or not [Assessing the problem of counterfeit medications in the United Kingdom.J ackson G, Patel S, Khan SInt J Clin Pract. 2012 Mar; 66(3):241-50). additionally making buyer separation between a unique medication and a fake form a troublesome.

In July 2015, the health ministry of India ordered the constitution of a subcommittee to investigate the issue of online pharmacies. The Committee has been constituted under the headship of the Food and Drug Administration (FDA) Commissioner of Maharashtra , Harshadeep Kamble. The issue before the subcommittee was the examination of the online deal rehearses did by created nations and how they have affected the public health in these nations and whether their execution is conceivable in India. The board has welcomed remarks and contributions from different partners, for example, stakeholders such as public companies, trade bodies amongst others The sub-committee has not submitted its report yet.(Anubhav Pandey 2017). Legality of Online pharmacy in India,Ipleaders,

Primary motivating factors that lead consumers to shop with online pharmacies include perceived lower cost (although some studies have identified higher prices from online pharmacies for certain classes of drugs and additional costs not associated with the drug's price), convenience i.e. 24/7 website availability , greater patient autonomy and perceived privacy from shopping online (Orizio G.Merla A Schulz,PJ, et al,2012.). Quality of online pharmacies and websites selling

prescription drugs: a systematic review complicating online health seeking and purchasing behavior are studies reporting low health literacy among potential consumers even when there are clear characteristics of patient safety risks present.(Mackey, Liang 2013)

With one click access to tens of thousands of online pharmacies and unlimited products to choose from, it is crucial for consumers to investigate whether the convenience outweighs the inherent risks of purchasing medicines online. However, confirming the veracity of an online pharmacy is also conflated by the use of falsified seals and fraudulent licensure information and accreditations, which may lure consumers into a false sense of security(Liang BA Mackey,2003) ,Searching for safety: addressing search engine, website, and provider accountability for illicit online drug sales

Why Social Media has revolutionized the Marketing Practices The philosophical and technological foundations of web 2.0, allow the creation and exchange of user-generated content, where a group of internet based applications structure on", is considered to be Social media (Kaplan & Haenlein, 2010). It has many advantages that help to develop and foster the connection between the businesses to consumer and strengthen the relationships in timely and at low cost manner (Kaplan & Haenlein, 2010). This social media has an uniqueness and its immense popularity revolutionalize marketing practices especially in advertising and promotional activities (Hanna, Rohm, & Crittenden, 2011) and patterns of Internet usage (Mangold & Faulds, 2009).

Consumer Behavior is also influenced by social media, by acquiring information from the post purchase behaviour of consumers, such as dissatisfaction statements or behaviors (Ross et al., 2009 and Laroche et al., 2012). To gain an increased sense of intimacy with the customers, companies use social media websites as an opportunity to engage and interact with them, which especially creates consumer loyalty (Mersey, Malthouse, & Calder 2010).

Most prompted industry leader's state that, the higher level of efficiency of social media, in comparison with other traditional communication channels, should participate in Facebook, Twitter, MySpace, and others, in order to succeed in

online environments. Thus, more industries including health industry also try to benefit from social media, as they can be used to develop strategy, accept their roles in managing others' strategy or follow others' directions (Williams & Williams, 2008).

A very few pharmaceutical social networking websites, permit consumers to not only exchange information about products or services, but also connect in co-creating value, in online experiences with offline outcomes, with both existing and potential consumers. Williams & Williams, 2008).

Besides, social media is extensively used to provide information, about dietary supplements and pharmaceuticals. With the introduction of devices, such as smart phones, coupled with government and private sector initiatives, the Internet is reaching almost every nook and corners of the country. Technology can help in meeting the healthcare objective of India (Market Research Report, 2013). In the present scenario, 120 million of populations are the active internet users and 900 plus millions are mobile phone users in India (Dinesh Chindarkar, 2015).

Though, online medicines look like a promising trend today, the business is challenged by regulatory issues. The developments in the pharmaceutical segment offer new ways, for individuals to online purchases of heath products and medicines. Almost, 31 start-ups related to online pharmacies were launched in 2014, with the major chunk of investment, announced by pharmaceutical companies like Netmeds ($60 million), followed by 1MG ($6 million) and Zigy ($3.2 million). This industry market, estimates to be generating 3,000-4,000 orders on a daily basis (Supriti, 2015). It is expected that, the online pharmacy model could account for 5-15%, of the total pharma sales in India, largely by enhancing adherence and access to the medicines, for a lot of the under-served population.

There is a continuous argument on the impacts of pharmaceutical marketing on health services conveyance. In a research study Civaner (2012) analyze the kinds of offers procedures utilized by pharmaceutical companies in the purchasers advertise and to pick up knowledge into the methods for staying away from the negative impacts of these methodologies recognize different deals techniques, both

legitimate and unlawful, are all around connected. These techniques target prescribers, patients, drug specialists, and society in general.

The most recent couple of decades have seen a dramatic change of the customer's part in health care services. The present time of buyer inclusion in health services harkens back to the medication market in the mid twentieth century when self-treatment was very esteemed and most medication promoting was pointed specifically at purchasers. Doctors' power over the recommending of medications has been straight forwardly tested by e-DTC promoting efforts asking buyers both to self-analyze and to request particular drugs from their supplier (Donohue, J. 2006).

Today's patient population is completely different from those of years past. They are involved, well educated and not afraid to question the advice of their physicians (Gupta and Udupa, 2011). Internet serves as a useful informational tool for consumers (Deshpande, Menon and Perri, 2004). Consumers are informed and aware of the medicines being promoted through different sources including internet and social media and are interested in their own health care decisions.

According to a research of UK 'medicinal services experts are progressively finding that they have more data accessible than they can deal with trust in their bustling time plans.(Roy A, Kostkova P, Catchpole M, Carson .E 2006).

Patients should seek the physician's opinion on the relevance and accuracy of information in DTCA. This would both strengthen the doctor patient relationship and avoid clinically inappropriate interventions (Murray, et al., 2003). If doctors believe that patients want and expect a drug then doctors will prescribe them even when it is not indicated. Some patients ask and doctors begin to believe that many patients will be dissatisfied without the advertised drug. Frequent misleading claims could reduce the credibility of true claims or cause consumers to exaggerate the safety or appropriateness of drug therapy (Hoffman and Wilkes 1999).

According to Myers (2011) physicians feel that that e- DTCA encourages consumers to seek medications that they do not need; it does not provide balanced information on costs, adverse events and alternative treatment options.

Landsman and Venkataraman (2013) found that patients increasingly request their physicians to prescribe specific brands of pharmaceutical drugs. Requests are triggered by direct-to-consumer advertising (e-DTCA) in different channels like print, radio, television or internet. It was found that although the effect of requests on prescriptions is significantly positive, the mean effect of DTCA on patient requests is negative. It was found that specialists receive more requests than primary care physicians but translate them less into prescriptions

According to Donohue (2006) Technological change has spurred an increase in health information seeking and self-treatment. Consumers use internet to collect information about their health and discuss with their doctors. Consumers accept that it makes them feel empowered to talk to their doctors. Because of the unique history of prescription drugs and physician's important role as intermediaries between drug manufacturers and patients for more than a half century, e- DTCA represents a challenge to physicians' roles as agents for their patients.

Majority of the physicians agreed that the info pharmaceutical companies provide on third-party websites for healthcare professionals "are always ads" for their products, and only few doctors trust the information pharmas provide on these websites. Physicians want more from pharma on these websites. It also revealed that some of the Physicians Believe Pharma Websites are not credible sources of information (Manhattan,2017).

Pharmaceutical advertisements harm the doctor–patient relationship in many aspects. Pharmaceutical advertisements do not always inform patients about the possible risks of the advertised products equally as they inform about their benefits (Cox and Cox, 2010).Patients may be purchasing drugs without professional oversight; some drugs may be unapproved or have safety concerns. Some online pharmacies have been found to sell counterfeit drugs resulting in patient death and injury(Liang , Mackey, 2009).

Seniors' request for a prescription as a result of drug promotions may complicate the relationship between the doctors and their patients. Moreover, majority of the respondents mentioned that they would consult another doctor or even change the

doctor is conditional with his/her refusal to prescribe online promoted drug (Grenard et al. (2011).

Additionally a study that examined the impact of TV and internet advertisement of medication for seasonal allergy of asthma found that majority of respondents have seen the advertisement and most of them interacted with their doctors asking them about the advertised medicine (Khanfar et al. 2008). on the contrary to that another study revealed that digital promotion had a positive and long-range impact on the number of visits to doctors (Liu and Gupta, 2011). Wilkes et al., (2000) study indicated that patients who asked for particular medication brands were just low in rate.

Online marketing and herbal products purchasing :

Herbal products are defined as "herbal preparations produced by subjecting herbal materials to extraction, fractionation, purification concentration, or other physical or biological processes. They may be produced for immediate consumption or as the basis for herbal products. Herbal products may contain excipients or inert ingredients, in addition to the active ingredients they are generally produced in larger quantities for the purpose of retail sales" (Thomas Nicholl and Coleman 2011)

The use of herbal medicinal products and supplements has increased tremendously over the past three decades with not less than 80% of people worldwide relying on them for some part of primary healthcare(Martins and Ekor, 2013).

Progressively more, alternative therapies such as herbal products are being used in the United States. Approximately 25 percent of Americans who consult their physician about a serious health problem are employing unconventional therapy, but only 70 percent of these patients inform their physician of such use(Eisenberg ,Kessler 2013)

India has known to be a center of Herbal brands also since the herbal products are profoundly connected with the spirituality sentiments of the people. A WHO (World Health Organization) contemplate estimates that around 80 percent of total populace relies upon common items for their health rather than modern drugs

principally due to side effects and highly expensive . (Sharma and Shankeet.al, 2018).

Herbal products are commonly marketed on the internet which was used by approximately 140 million individuals in the United States in 2001(Marcus.2002).

Unlike conventional drugs, herbal products are not regulated for purity and potency. Thus, some of the adverse effects and drug interactions reported for herbal products could be caused by impurities (e.g., allergens, pollen and spores) or batch-to-batch variability. In addition, the potency of an herbal product may increase the possibility of adverse effects.(Dietary Supplement Health and Education Act of 1994.) The worldwide herbal market products are around $6.2 billion and estimated to reach $5 trillion by the year 2050 (WHO & Kotler ,2008). Drugs could be miscellaneously classified-Orphan drugs, Ethical drugs, Generic drugs, Lifestyle drugs, Diagnostics, Neutraceuticals, Personal Care Products, etc. India has a very long, safe and constant tradition of many herbal drugs in the authoritatively standard alternative systems of health *viz*. Ayurveda, Yoga, Unani, Siddha, Homeopathy and Naturopathy. These systems have fairly existed next to Allopathy and are not in 'the domain of obscurity', as stated by Venkat Subramanian (2011).

Many Ayurvedic companies in India produce pharmaceutical products, nutriceuticals products and also FMCG like soaps, shampoos, toothpaste, toothpowder using traditional herbal ingredients and promote these products in various channels like magazines, Radio, Television and Digital media (Vaijayanthi et al., 2012).

 In purchasing herbal products online, the consumers need to have previous product knowledge with the herb that is being sold online and some knowledge on how to use computers and the internet. Previous and after experience in purchase are noteworthy predictor to trust for e-Commerce (Chow. and Angie. 2006).

In a survey of 20 Indian drug makers that the Indian Pharmaceutical Industry is sweeping across Rs.1036 billion market shares and is entering into the digital waves of promotions. The study also indicated that, mobile apps and social media

are playing a wider role in this industries' growth. Companies are very well emphasizing, on monitoring the discussions going online, about the products. (Prabha Raghavan ,2016)

Prior experience are consists previous usage of online herbal products, herb purchase and internet usage. Previous product experience is a noteworthy sign of behavior on internet shopping (Klein 2008).

Ayurveda meaning, "the knowledge for long life" is a traditional system of indigenous medicine in India ,and is viewed as an alternative medicine. It is a function of modern and traditional knowledge systems. India's Ayurvedic medicine is losing market and needs new marketing strategy. It is losing its global market to China and has registered a fall in the export of ayurvedic medicines (Valiathan, 2006).

In India, the traditional herbal medicines, such as Ayurveda, Siddha, and Unani (ASU), are considered safe because of their long history of use. As such, no safety and efficacy studies are required for marketing approval, as per the Drugs and Cosmetics Act of 1940 (DCA).

Online marketing and herbal dietary supplementary and nutrients consumption

Dietary supplements and herbal remedies   are popular complementary or alternative products for people. These are the supplements that are intended to supplement the diet and contain one or more dietary ingredients (including vitamins, minerals, herbs or other botanicals, amino acids, and other substances) or their constituents. These are intended to be taken by mouth as a pill, capsule, tablet, or liquid and are labeled on the front panel as being a dietary supplement. Such products may range from isolated nutrients, dietary supplements and diets to genetically engineered "designer" foods, herbal products and processed foods such as cereals, soups, and beverages.(Schroder, 2015).

These botanicals are sold in many forms as fresh or dried products, liquid or solid extracts, tablets, capsules, powders, tea bags, and so forth. For example, fresh ginger root is often used in various food stores; dried ginger root is sold packaged

in tea bags, capsules, or tablets, and liquid preparations made from ginger root are also sold in the market. A particular group of chemicals or a single chemical may be isolated from a botanical and sold as a dietary supplement, usually in tablet or capsule form. An example is phytoestrogens from soy products ([36].

Nutritional supplements are usually offered in an untypical form of food, including tablets, capsules, powders, or pills. Although many individuals use supplements, those engaged in sport and physical activities were found to represent an important portion of people purchasing supplements (Maughan,2011)

Media, including books, magazines, television, and internet, was also perceived as a powerful influence on a person's decision to use nutritional supplements .Media, including internet, media, magazines, and books, influenced the decision making of 60.8% of participants in the current study. Magazines, newspapers, and internet were also the major sources of information about supplements(Conner,2013).

The Internet is a tool perfectly suited to the marketing of herbal dietary supplements. There are a great many websites that sell supplements and they send out millions of spam e-mails (Norman 2013).

The marketing strategies and efforts by various manufacturers of herbal medicines and their sales representatives have seriously projected these products into greater limelight. Various advertisements in the mass media including television and radio programmes and digital media have significantly increased consumers' awareness and given the herbal products undue respectability and credibility (Brevort, Parle and Bansal, 2006).

Internet marketing and sales are in part responsible for the growth and development of the natural dietary supplement industry over the past decade. National survey data collected from 2003 to 2006 indicate that 53% of US adults report dietary supplement use .Consumers can easily find information about dietary supplement over the Internet and on social networking sites such as Twitter and Facebook (Bailey RL, Dodd ,2010)

supplement users in several surveys reported that books, magazines, Internet ,health food stores and even fitness and/or nutrition classes were more useful sources of nutrition information than were physicians or dietitians/nutritionists (Barr Levy and Schutz et al.2008). Moreover, Levy and Schucker (2008) reported that individuals who consumed more than two supplements daily were less likely to rely on physicians than were individuals who consumed less than two supplements daily.

Children are encouraged to use herbs for their nutritional values to facilitate normal or healthy growth and development; young persons for their euphoric effects, supply essential ingredients to help them cope with daily stress and to prevent or slow the onset of aging; older persons for their anti-aging or rejuvenating effects and women for slimming and beauty enhancing effects (Parle and Bansal, 2006).

Even though the fact that herbal drug use is common amongst patients and they can adversely interact with drugs, various studies have found low patient disclosure rate of herbal usage to the doctors. This may be because of lack of communication between patients and doctors or because of patient's unawareness about their potential toxicities and possible drug interactions.(Saw and , Bahari etc al ,2006)

Herbal drugs for COVID-19 and consumers:

While the number of Covid-19 cases increases in India, people are more and more turning to ayurvedic drugs and products in the expects of boosting their immunity. (Anjali Venugopalan,2020). This is most manifest in China and India, health officials in China are recommending traditional herbal remedies for COVID-19, but many experts warn that we don't have enough data on COVID-19 to understand how different herbs may affect people's health.
Though herbal drugs may no side effects, if misused, they could increase a person's risk for COVID-19. Some researchers may find that certain herbs are effective in preventing and treating COVID-19 in some people, but there currently no enough data regarding the use of herbal remedies for the covid-19.(22) .But in major medical journals published reports that large numbers of patients treated in

China make not mention about alternative drugs. But ,they revealed that treatment revolves around popular treatments such as respiratory support, drugs to help prevent other infections such as bacterial pneumonia and other widely accepted therapies.(15). Promoting treatments with alternative drugs without an adequate scientific basis is worrying some of these preparations can be toxic, harm the liver or interfere with other drugs and you need to do the hard work to prove them safe (Dr. Daniel Kuritzkes, 2020).

Pharmaceutical companies like Himalaya, e-marketplaces such as Grofers and Milkbasket, as well as new age ayurvedic health brands like Auric announced that they were witnessing a surge in sales that could be attributed to the corona virus concerns.
Milkbasket said online sales of products like honey, chyawanprash and herbal teas which are touted to improve immunity had increased 17-18% month on-month. January and February are usually the months with the best sales of these products, as most of North India

Auric, a brand of new-age ayurvedic health drinks, said apart from the regular expansion in sales, an additional 30-35% increase was there which he attributed to the corona virus scare. The company's immunity drink, 'Body defence', is now pushing up the sales in online rather than the drinks that aimed at skin rejuvenation and boosting hair which used to sell more earlier. "Earlier, people want to look good and then feel good," but now it is reverse.(Deepak Agarwal,2020).

While sales of Himalaya's hand sanitisers and hand wash have gone up ten times in the last few weeks, sales of the company's immunity tablet, 'Guduchi', has gone up three times as well. Delhi, Madhya Pradesh, Punjab, Haryana, Uttar Pradesh and Gujarat are driving the demand, said Himalaya Drug Company CEO Philipe Haydon.
The public can easily purchase herbal drugs without a doctor's prescription in stores and online also . Most of the people rushed for the herbal drugs with flu symptoms who fear quarantine measures are likely to self-medicate with herbal drugs and avoid going to hospital, thus delaying the proper diagnosis and treatment

of the disease, and hampering the government's testing, tracing, and quarantining efforts.

At the end of January, 2020, rumours circulating on social media suggested that a patent herbal drug called Shuanghuanglian, which contains honeysuckle and forsythia and is used routinely in traditional medicine to treat influenza and the common cold, helps ward off or even cure COVID-19. Millions of people nationwide crowded into drug stores to buy the herbal drug as a just-in-case remedy. Yichang Yang,2020)

The Ministry of AYUSH released an advisory in January about the ayurvedic, homeopathic and unani ways of managing the outbreak. While it also included WHO guidelines like handwashing and using masks, it listed out a number of herbs and other formula that could be adopted by people.

Against this background   though a lot of research has been carried out in different countries on online pharmacy marketing and their impact, data on herbal and supplementary pharmaceutical marketing strategies like India is still lacking. There is a need for more and more research on awareness levels, perceptions, attitudes, responses and consumption of the patient population and doctors which are the key targets of a majority of pharmaceutical marketing strategies.

 Not only allopathic pharmaceutical drugs have been a major online product but also herbal and supplementary medicines are being sold at an equal rate. But then there has been no such research on the marketing of herbal and supplementary medicines as there is on the allopathic.

A strong evaluation and awareness that is created towards the perception, attitudes and behavior of the key target consumer groups regarding digital media marketing by pharmaceutical industry may help to fill the gap and revolutionize the contemporary pattern of using on the web for purchase of herbal and supplementary products.

So, there is a need for more critical research in this area to understand the online media marketing of herbal and supplementary pharmaceutical industry and its impact on drug consuming behavior of the public.

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Reflections of Ayurvedic Practitioners on Using Online Herbal Drugs

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Herbal medications have a long history in India, and the country is the world's greatest producer of medicinal plants. The use of herbal drugs as supplementary medicine has improved over the years for various reasons which include the wide coverage of Ayurveda products, acknowledgment of modern science, disparities in the healthcare system, and government efforts. The increase in useof the internet and the availability of more herbal products online havealso greatly influenced consumers' purchasing decisions for herbal products.

Herbal products are one of the most extensively utilized supplemental and alternative medicine therapies worldwide. Traditional and complementary medicine (T&CM), according to the World Health Organization, can make a substantial contribution to the aim of universal health care by being incorporated in the delivery of essential health services. India exports medicinal herbs to 164 nations in total. Herbal remedies can be made from over 8,000 medicinal plants. Ayurveda, Siddha, and Unani are three historic Indian medicinal systems. Medical systems are described in the Vedas and other ancient religions. Between 2500 and 500 BC in India, the Ayurvedic philosophy emerged and developed Because the ancient Indian system of health care focuses on ideas of man and his ailment, Ayurveda literally means "science of life."

The traditional medicine market is set for substantial growth in the coming years. The increasing acceptance of traditional medicine practices in developed regions is expected to propel market expansion. Furthermore, a rising consumer preference for natural and plant-based remedies is a key market driver. Additionally, escalating healthcare costs will likely encourage consumers to turn to more affordable traditional therapies.(Neha Joshi, 2024).

Today, herbal products that combine modern scientific techniques with traditional knowledge are finding increased applications in drug discovery and development. There is a growing global demand for herbal drugs, which are widely used around the world. Herbal medicines are preferred by many due to their higher therapeutic effects and fewer side effects. A significant portion of the population favors herbal medicine.Santosh , Dighe et.all.,2023).

The modern Digital information media has become an essential part of life. Like in every industry, digital marketing is replacing traditional marketing techniques in the pharmaceutical industry. This is mainly to give relief of interaction with end users, it is not a time-consuming engagement and is cost-effective too (Dhara, et. al, 2016). In addition, digital marketing made doctorsuse social media and other digital tools.

There are a lot of commercial websites available on the Internet, which declare that herbal medicines have no side effects. The manufacturers of herbal medicines carry out various marketing strategiesand their sales representatives publicized these products into the greater limelight. according to astudy increases inhealth awareness, changing trends of self-grooming, lifestyle changes, confidence and trust in Ayurvedic medicine as asupplementary system, and increased broadcast of mythological series on airare some of the factors that have led to a boom in the herbal products industry (Unnikrishnan, 2019).

Studies conducted by MICA reveal that there is anincreasing preference by consumers for herbal or natural products over other cosmetic products, and an increasing acceptance of Indian herbal products in the international market is seen.(Apsara Wijenayake etc, 2021).

Online herbal marketing and purchasing habits:

With new developments in technology, herbal products, and services are being offered to customers in a number of ways. The products can be spotlighted as medicines or food supplements or food products. They can be therefore sold through herbal specific pharmacies, general pharmacies, store and non-store (on-line and social media) retail formats. Herbal products are sold through both organized or formal and unorganized or informal retail formats. In recent times, sale of herbal products through e-commerce is an increasing trend. A manufacturer can show their products as Ayurveda, herbal, natural or organic based on the market demand. The market demand is surging for all these categories and tough competition has been seen among them. Majority of companies are using technology to offer herbal services and few of them provide both products and services.

With the emergence of the digital growth wave, digital penetration through better internet access, improved security of payments gateways, e-commerce adoption, and Cash on Delivery (CoD) options are the main reasons of the increasing of online market for herbal drugs and changes in consumer behavior also lead to more online herbal market. This is demonstrated in a recent FMCG segment, which shows that within the personal care market alone, the growth of natural product sales is 2.2 times greater than that for non-naturals. (Nielsen Report, 2021).

Children are being encouraged to use herbal products for their nutritional values to facilitate healthy growth and development; Young people for their ecstatic effects and to cope with daily stress and to avoid or slow the onset of aging; older people for their anti-aging or rejuvenating effects and women for slimming and beauty magnifying effects (Parle, 2020).

A study on herbal and alternative medicines from 2015-16 showed even greater rates of quality problems. The 2015-16 data shows an 80% non-compliance rate overall, primarily due to labeling, advertising, and evidence problems (Harvey, 2016). While some herbal medicines have promising potential and are broadly used, the majority of them remain untested and their use is also not monitored. Several advertisements ondigital mediahave noticeably increased consumers' awareness and given herbal products have unproven respectability and credibility (Bansal, 2019). The dearth of suitable quality controls, inadequate labeling, and the absence of appropriate patient information and the safety of most herbal products is further compromised(Raynor et al., 2021).

With the digitalization of Ayurveda, there is much greater transparency and sharing of information. Quality control standards that have been introduced by the Ministry of AYUSH are also helping raise consumer confidence, as manufacturers can now ask for certification with labels like AYUSH Premium Mark and AYUSH Standards Mark. Now, consumers and patients can also communicate directly with qualified experts and with manufacturers to learn more about product ingredients, applications, and dosages (Bali, 2018).

Herbal medicines are shown to be free from side effects. This is a myth. A study from 2015-16 found even higher rates of quality problems in herbal and alternative medicines. "The 2015-16 data shows an 80% non-compliance rate overall, primarily due to labelling, advertising and evidence problems" (Harvey, 2019). A lot of commercial websites can be found on the internet, which insist that herbal medicines have no side effects. In underdeveloped and developing countries, there are no specific laws for herbal practitioners and companies marketing herbal products. People are attracted by such companies and begin using herbal products in the false belief that herbal products are free from side effects.

The third area of concern is the filling of prescriptions generated by online physicians who obtain patient information solely from online questionnaires that may have checkboxes that are preselected for the response that helps the patient obtain the medication in question. This blueprint of care is concerning because patients may use these online physician services to obtain medications for symptoms that they may not have disclosed to their local provider. On the other hand, cyber doctors provide medication via the Internet that addresses their complaints.

As resource centers for herbal, ayurvedic or natural information, the leading herbal e-commerce platforms also provide a rich repertoire of herbal knowledge, along with information on on-going studies and research. This helps strengthen consumer confidence and keeps patients informed about what really works and what doesn't. When it comes to the digital market for herbal products, one of the most significant features that increases transparency is the easy access to patient

testimonials and reviews. With better user engagement and two-way communication, manufacturers also benefit, as they are able to review, update, and introduce products, based on user feedback

Bonding to our prescription usuallyentails taking our drugs as directed by our doctors, in the correct dose, at the correct time, in the correct manner, and with the appropriate regularity. These are the basic actions to do; failing to take our medicine as recommended by a doctor or as directed by a pharmacist may result in our sickness worsening, hospitalisation, or sometimes lead to death.

So, it is very important to take suggestions for consuming any health products either prescribed or herbal drugs. So, for the study to be more aware of online herbal drugs and supplements, in-depth interviews were conducted with Ayurvedic doctors in Hyderabad and Tirupati to draw opinions and suggestions on online herbal pharmacy marketing.

The Ayurvedic doctors were chosen to provide perspectives on online herbal drug promotion practices. In the interview, the doctors have given valuable suggestions and information to consumers about the online herbal products and supplements. From the in depth interviews the following suggestions were drawn.

Herbal products and supplements:

A plant or plant part utilised for its aroma, flavour, or therapeutic characteristics is known as a herb. One sort of dietary supplement is herbal medicine. Tablets, capsules, powders, teas, extracts, and fresh or dried plants are all available. Herbal remedies are used by people to try to maintain or improve their health.

The vast majority of individuals believe that "natural" products are always safe and beneficial to them. This isn't entirely correct. Herbal remedies are not subjected to the same rigorous testing as pharmaceuticals. Some herbs have the potential to inflict serious harm. Some plants have the potential to interact with prescription or over-the-counter drugs.

Herbal supplements are meant to help people stay healthy or treat illnesses. They are not, however, controlled by CDSCO. Herbal supplements are considered food by the Central Drugs Standard Control Organization (CDSCO), not drugs. The label of a herbal supplement can state how it may benefit, but it cannot claim to be a cure for a condition or ailment.

Digital doctors and patients :

Accessibility: In addition to scarcity of doctors and hospital beds, 60% of hospitals, 75% of dispensaries and 80% of doctors in India are located in urban areas servicing about 28% of population causing severe accessibility problem. Over 48% of Indians in rural areas need to make overnight trips

for Health & Medical reasons. Accessibility is not just a rural, tier II or tier III issue. Even in Tier 1 cities, it takes an average of one to two hours to consult a good doctor due to heavy traffic and long wait times at the clinic or hospital. This leads to postponing or neglecting one's health issues which over time get exacerbated into serious diseases.

Telemedicine can reduce the time it takes to consult a doctor to 10-15 min in both rural and urban areas by cutting wait times through optimal utilization of doctors and by avoiding the need to travel to a clinic or hospital, at a fraction of the cost of current healthcare systems. Electronic Medical Records (EMRs) can digitalize patient's information coming from various sources at one place helping doctor to make an accurate prognosis in a shorter time

As Telehealth services continue to become more popular across the world researchers are beginning to explore the effectiveness of virtual doctor's visits as opposed to a traditional clinical appointments.

n 2018, telemedicine has expanded in India. It has undertaken a new way for doctor consultations. This sector is at an ever-growing stage with high scope of development. This rapid growth in the last year presents telemedicine as the next frontier in the healthcare. The year 2019 will be an important year for telemedicine industry. Health data is useful in many ways and one of them is AI (Artificial Intelligence). In future, this will help in identifying issues related to medical health. Through IOT (internet of things) perspective medical emergencies like Asthma attack, heart failure, diabetes can be monitored via connected devices.

Telemedicine is the roadmap for improved medical care in rural areas. NITI Aayogya states that, the National Health Stack (NHS) is a virtual digital platform for healthcare in the country. NHS study aims to have digital health records for all citizens by 2022 to make telemedicine and E-Health easy. However, with the introduction of Ayushman Bharat Scheme, a biggest health financing scheme, Indian government has come up with ICT (Information and Communication Technology)focusing on the development of health sector in the country. This scheme includes Tele-health development ideology for long distance medical care to make a safe, effective, efficient, patient-centered and timely health management environment.This integrated market of telemedicine platform will have a mix approach in the coming year. In a developing country like India, there is a lot of room for development. With the communication industry evolving at such a rapid pace, telemedicine sector is bound to develop too.

Safety information about online herbal drugs and supplements

Because herbs come from nature, they aren't always safer than the components in over-the-counter (OTC) and prescription medications. Several prescription drugs are substances that have been refined

from natural sources. Although herbal health supplements and products are labeled as "natural," their contents aren't always natural to the human body. They could have a major impact on your body.

In various parts of the world, herbal drugs and medicinal plant products have been widely used for thousands of years. Medicinal plants compose a source of raw material for both traditional and modern systems of medicine.

About 60% of the world's population uses alternative medicine. The rural masses use these medicines for their primary healthcare in developing countries, but it is also seen that these are also used in developed countries which are dominated by modern medicines(Ballabh and Chaurasia, 2017).

Herbal products and Prescription medicines

Herbal products or supplements can, without a doubt, influence how the body processes medications. It's possible that your medicine won't operate properly as a result of this. The drugs may not be absorbed in high enough levels to help the health issues for which they were given if this happens. This can lead to major issues. Before using any herbal health product or supplement, consult your doctor if you are taking any OTC or prescription medications.

Online marketing and herbal products purchasing:

Worldwide there is a growing demand for Ayurveda and other traditional forms of medicine (World Health Organization ,2012).In India, about 80% of the rural population uses medicinal herbs or indigenous systems of medicine (Mukherjee and Wahile ,2016). It is estimated that nearly 960 plant species are used by the Indian herbal industry, and the turnover of the industry is more than Rs 80 billion. Herbal exports include medicines of AYUSH (Ayurveda, Unani, Siddha and homoeopathy) products, which occupy a share of 3% of total Indian pharmaceutical export. Seventy percent of export from the herbal sector consists largely of raw materials and is estimated to be Rs. 10 billion per annum. Thirty percent of the export consists of finished products, including herbal extracts (Government of India Planning Commission. Eleventh Five Year Plan (2007–2012).

Adverse effects of herbal drugs and supplements

The majority of individuals believe that all herbal medicines are safe and beneficial. However, while many herbal medicines have evidence-based good efficacy safety profiles, one must be careful of numerous negative effects such as toxicity, overdosage, and herb contamination.

Highlights of the Doctors opinions on effects of online herbal drugs on consumers

Against this backdrop, we interviewed Ayurveda Practitioners in Tiruapti, Hyderabad, in-depth. The purchase habits of consumers who buy herbal drugs online and its effects on their health have been discussed by ayurvedic practitioners. These are some of the significant issues that the practitioners of ayurveda have addressed.

General Physician, M.D. (Ayurveda), Sri Venkateswara Ayurvedic Hospital. Tirupati.

"*Although many herbs are primarily of historical interest, thousands of herbal products are available over the counter and commonly used by patients Therefore, an understanding of the composition, regulation, safety and efficacy of herbs may assist doctors in advising patients about the use of these products*".

A Private Ayurvedic Practitioner M.D. Ayurvedalaya, Hyderabad

"*The unethical publicity have led to fake advertisements about the safety and efficacy of the herbs reaching the public today more so than at any other time. Herbal products are advertised in magazines, newspapers and books, on radio and television and through the Internet. Herbs are suggested for treatment on the basis of unproven, word-of-mouth traditions and beliefs. In Some advertisements can described that the featured product is "doctor recommended," "the world's most powerful," "patented," or "now presented without a prescription"*

General Physician MD Ayurveda Govt. Ayurvedic College,

"*Ayurvedic medicines are India's oldest and a traditional medical system for treating illnesses. These medicines are referred to in ancient writings which majorly consist of plant product and may include animal product, metal, and mineral. So, without consulting the physicians using of herbal/ ayurvedic drug is not safe*".

Ayurveda Physician, M.D. Ojus Ayurvedic Center Hyderabad.

"*In general, herbal drugs are safe but sometimes they may cause side effects. These can include stomach upsets, sleeplessness, and pains in your muscles or joints. Some herbals may also interact with your prescribed drugs. If you are thinking of using these herbals drugs ,always buy them from a trusted manufacturer to make sure they are a quality product either in stores or online and discuss their use with your doctor first*"

Ayurvedic Physician, M.D.AyurvedaDathuAyurvedam,   Hyderabad

"*Since herbs are plants, they are often perceived as "natural" and therefore safe. however many herbs may show side effects from biologically active constituents from herbs, side effects caused by contaminants and herb–drug interactions. So, when ever purchasing online herbs or from stores everybody should be more cautious and conscious*".

General Physician, BNYS Hyderabad

"*Herbal medicines are easily available in market and can be purchased without prescription. These products are advertised on media as a miracle treatment without any side effects to attract people. Online companies selling these products misguide people and claim their product totally free from adverse effects. Even there is no period mentioned, some people continue for months or years, which in long term can be harmful for patient's health*".

Physician BUMS, MD – Medicine, AYUSH, Unani, Hyderabad

'It is very important that consumers do not self-diagnose any health problems, and that any drug, whether herbal or not, is used under the supervision of a competent and qualified practitioner.'

Ayurvedic Doctor, BAMS, Tirupati.

"Many herbal products did not carry adequate warning labels about side effects and drug interactions. Pharmaceutical companies are required to list all side-effects and possible drug interactions on their products."

Doctor, Prakruti Ayurvedic Medicals. Tirupati

"Not all herbal medicines that are sold are safe. Always buy from a source that stocks products from a reputable manufacturer or supplier, such as health food stores, supermarkets, pharmacies or from a reputable brand websites."

Senior Consultant Expert In StriRoga& Shalya, Hyderbad .

*Many individuals assume that "all natural items are safe," and that "natural herbals are absolutely risk-free." Patients who take herbal products and other medications at the same time, as is common, sometimes fail to inform their doctors about their herbal medicine use. Patients rarely tell their herbal medicine providers about any other prescriptions they're taking, either. As a result, it will have numerous negative consequences. Patients frequently become confused when purchasing or using herbal drugs online, and as a result, they abruptly stop usingthem."*Consultant Expert in Ayurvedic Internal Medicine & Panchakarma, Hyderabad

"Becareful about purchasing herbal medicines online un regulatedherbal medicines from overseas may not be manufactured to the same quality and standard as regulated medicines. In some cases, products purchased online have been found to have dangerous levels of metals or arsenic, which can cause serious health problems. Many patients use these herbals without physician's consultation, but dosage is more important but all consumers ignore the dosage of the herbals which is worthless"

The doctor from Sri Venkateswara Ayurvedic Hospital. Tirupati.in the study opined that*"Because herbal pharmaceuticals are derived from nature, they are not always safer than the components in over-the-counter (OTC) and prescription drugs. Several prescription drugs contain substances that have been refined from natural sources. Although herbal health supplements and products are labeled as "natural," their contents aren't always natural to the human body. They could have a significant impact on your body. They can also have negative consequences.".*

A private Ayurveda physician, explained *that in general every medicine, even herbal drugs are also show side effects in some patients. Any herbal doctors should not suggest such herbal drugs for patients without knowing or checking patients personally. As per charakasamihita, after checking the nadi (pulse) of the patient and based on the patient's body tatva (vata, kappa and dosha), only doctor should suggest the drug.*

A private ayurveda practitioner about the baby herbal products online "*Opined   that it was not good to use such soaps or hair oils and skin oils for body massage which may produce lots of side effects for babies like irritation, rashes or skin allergies*".

When buying and using herbal drugs from internet vendors, customers should keep in mind the following advice provided by the Ayurvedic practitioners..

Precautions when choosing herbal drugs or herbal supplements

- Herbal drugs and supplements can interact with prescription medications or have significant side effects. Do not try to diagnose yourself. Before taking herbal supplements, consult your doctor.

- Get as much information as possible about the plants you're taking by talking to your doctor and contacting herbal supplement producers.

- If you take herbal supplements, read the label carefully and only take the recommended dosage. Never take more than the recommended dosage, and find out who should not use the supplement.

- Keep an eye out for negative side effects. Reduce the dosage or stop using the herbal supplement if symptoms such as nausea, dizziness, headache, or upset stomach occur. Also, talk to your family doctor about it.

- Be aware of the firm from which you are obtaining your herbs. All herbal supplements are not made equal, so it's best to stick with a well-known brand.

Questions to ask doctor about herbal drugs or herbal supplements :

- How do I know when and how to take herbal medications?
    - How do I know how much herbal medicine or supplement I should take?
    - Are there any herbal supplements that would be good to me?
    - Will any natural drugs or supplements interact with any of my current medications?
    - Are there any adverse effects from natural medications or supplements?
    - Is there anyone who should avoid taking herbal medications or supplements?
    - How can I pick the best natural medicines and supplements?
    - Can I take herbal medicines or supplements if I'm pregnant or breastfeeding?
    - Are there any natural medicines or supplements that are safe for children?

Herbal medicines are known by many names in various nations. As a result, even if the titles may sound similar, wecannot be certain that the packages contain the same contents.

If we areunsure about a medicine, see a medical specialist, go to the pharmacy, or compare the active ingredients to a medicine you're familiar with.

CONCLUSION

This study uncovered information about customers' online purchases of herbal drugs and supplements, as well as their interactions with doctors about these issues. Doctors' discussions on online herbal medicine use tend to be rare, and the main limiting issues identified appear to be a lack of awareness of the importance, as well as doctors' failure to ask, explain, and be approachable.

The reasons for obtaining herbal medications and supplements online were revealed as a result of this study. The majority of customers are unaware of herb-drug interactions and the need to report side effects, which is a major problem.

The truth is that the terms "safety" and "natural" are not interchangeable. As a result, It is necessary to standardize and enhance global regulatory policies on herbal medicines. Relevant regulatory agencies in various countries throughout the world must take aggressive steps to protect public health by ensuring that any herbal medicines licensed for sale online are safe and of acceptable quality.

 Healthcare providers like Doctors, nurses, and pharmacists, sometimes lack expertise and understanding of how online herbal medications affect their patients' health. Many of them also have limited knowledge of these products and how they are used. Since most patients are nearly always on different sorts of prescription or non-prescription online herbal drugs, adequate training is now very important.

Self-medication is highly popular in India, and it is becoming a growing concern for health care practitioners. Health providers must devote additional time to educating patients on the subject. Improved self-medication knowledge and comprehension may lead to more reasonable use and, as a result, a reduction in emergent microbial resistance concerns.

As discussed earlier online herbal market has a few advantages to offer such as online consultation, safety information about side effects and security of the drug description, ingredients, time saving, reduced drug prices, increased availability, and widened choices of medicines or delivery at home are major factors that are influencing the consumers to choose the online herbal drugs.

This study examines how customers use herbal items obtained over the Internet and their perceptions of their safety and hazards. The study's findings highlight the critical need for consumers to be more aware of the risks of purchasing herbal items over the Internet. There is also a need to educate consumers about reputable licensed herbal pharmacy websites where they can purchase herbal products. The majority of respondents bought herbal items and supplements online, citing inexpensive prices, convenient online access, a broad selection of products, and customer privacy as the primary reasons.

 Based on the report of the consumers in the survey, it was found that the information was confusing and unclear with less description so, the physicians should help the consumers to know more details about online herbal drugs.

To avoid becoming victims of false or propaganda information on herbal pharma websites, consumers will need to learn information literacy skills and critical understanding in examining the content of information on herbal pharma websites.

Consumers should be educated about internet herbal drug ads, according to proponents of online health drugs. They claim that these commercials increase market competition, lowering prices and that the educational benefits enable customers to make better decisions, so increasing public health and lowering healthcare expenditures.

Self-medication is a frightening thought, the study looked at how customers used online herbal remedies for self-medication, how safe they are, and why they used them. As a doctor in the study explained, *it would be safe if those who use it were aware of the dose, timing of consumption, and side effects of overdosing; nonetheless, a lack of understanding can result in major side effects such as skin problems, hypersensitivity, and allergy.*

Consequently in the study, doctors suggested that a holistic strategy be adopted to address this problem, which includes proper awareness and education about self-medication as well as stringent enforcement of online herbal drug laws. Thus collaborations at the global, national, and state levels, as well as among health professionals, society, and patients, are required to address the considerable threat posed by the increased ease of access to online herbal purchases

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EMPOWERMENT OF SCHEDULED CASTES (DALITS) THROUGH ENTREPRENEURSHIP : A STUDY ON DALIT BANDHU SCHEME IN TELANGANA STATE

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"One of the most effective approaches to mitigating poverty, enhancing living standards, and fostering job creation on a global scale is to promote greater openness and freedom within economies and governments. This strategy serves to incentivize business activities and entrepreneurial endeavors, ultimately yielding positive socioeconomic outcomes."

- Elliott Bisnow

ABSTRACT:

The eradication of poverty consistently presents itself as a formidable problem within economic progress. Individuals affiliated with the scheduled castes represent the most marginalized and socially disadvantaged segments at the lowest rung of Indian society. The practice of "untouchability," considered very inhumane, has historically been identified as the primary factor responsible for the horrible conditions experienced by this particular group of individuals. The state of underdevelopment can be attributed to both economic and social factors. The Government of Telangana has acknowledged the longstanding and significant injustices certain segments of society face. In response, they have formulated a groundbreaking initiative called the 'Dalit Bandhu' scheme. This program aims to facilitate substantial economic progress for scheduled caste families, ultimately ensuring their social dignity. This study investigates the key elements of the Telangana Dalit Bandhu Scheme 2023, obejective, benefits etc. and also to understand the underlying factors contributing to the entrepreneurial success of Dalits.

KEYWORDS: Telangana, Scheduled Castes, economic development, social dignity, Entrepreneurship.

INTRODUCTION

Throughout the past seventy years, individuals belonging to the Dalit community have consistently occupied the lowest stratum of the socio-economic hierarchy. Yet, there needs to be more significant progress in health and education.

The 1931 Census marked a significant milestone by systematically categorizing specific castes as "depressed classes" for the first time. Subsequently, the Government of India Act 1935 introduced a significant provision for identifying socially disadvantaged castes as 'Scheduled Castes.' Consequently, the Government of India officially published a comprehensive list of such castes (Scheduled Caste Order, 1936). The historical origins of the classification of certain castes as Scheduled Castes may be traced back to the enactment of the Government of India Act in 1935. The action above, undertaken by the British Government at the time, aimed to provide unique political concessions to the most oppressed and exploited castes. Most of these castes were commonly referred to as "untouchable" within the

framework of the Hindu social hierarchy. The category of Schedule Caste originally consisted of those who were socially marginalized and disadvantaged due to their status as "untouchables."

The term "Scheduled Caste" is legally defined in Article 366(24) of the Constitution of India. It refers to specific castes, races, tribes, or subgroups within these categories that have been officially designated as Scheduled Castes under Article 341 of the Constitution. Scheduled Tribe groups are distinguished by their unique cultural practices, geographical seclusion, limited interaction with the wider population, and socio-economic disadvantage.

The 2011 Census reveals that around 18.44% of India's total households, amounting to 331 million, belong to oppressed and marginalized parts of society. These homes have endured neglect and disregard within the social fabric for centuries. Indian society is characterized by marginalization, encompassing many groups such as Dalits, backward classes, and women, each with distinct socio-economic traits and challenges. India continues to grapple with the persistent presence of the caste system, even more than 75 years following its attainment of independence. Dalits remain the most susceptible, marginalized, and oppressed population in the nation.

This study is conducted with the objective of comprehending the process by which scheduled castes achieve empowerment through engaging in entrepreneurial endeavors. The phrase 'scheduled caste' has been employed as a legal classification since the enactment of the Government of India Act in 1935. During this time, the British administration included the Hindu castes occupying the lowest social status in a Schedule attached to the Government of India Act. This was done to provide them with statutory protections and various other advantages. Though, M.K.Gandhi called these people as Harijans (Sons of God), 'Dalit' is substituted in political parlance and scheduled caste is opted for statutory provisions, government programmes, and other benefits, but the plight of these marginalized sections have not been changed drastically.

Entrepreneurship plays an important role in achieving the goals of development in general and industrial development in particular. In Indian context, provision of employment opportunities and job creation is a foremost challenge the country is facing in the economic front. India possesses a substantial demographic advantage, offering enormous potential for fostering innovation, nurturing entrepreneurs, and generating employment opportunities for the well-being of its vast population. In recent times, the Indian government has launched a wide array of new initiatives and established numerous opportunities to promote innovation across various sectors. As a sequel there is a need for creating awareness among the general public and most importantly among the marginalized communities for taking up entrepreneurial activities fostering inclusive economic growth and for creation equality of opportunities in India.

Thus, entrepreneurship is considered as an essential for self-reliance and bringing progressive change in the life styles of people of the country marginalized for centuries. Therefore, the Government of India and state governments shall have to promote entrepreneurship by mentoring, nurturing and facilitating for easy access to financial institutions. As the good governance initiatives in public sector, in provision of services, is not matching with the public demands and expectations the alternative is to encouraging

entrepreneurial initiatives.

Objectives
The study will be conducted with the following objectives:
- To examine the socio-economic conditions of Dalit Entrepreneurs.
- Problems and societal constraints faced by Dalit Entrepreneurs.
- To study the Dalit participation in entrepreneurial activities.
- To study the objective, benefits , implementation and constratints of Dalit Bandhu scheme .

Methodology: The study mostly relies on secondary data sources. The secondary data was obtained from reports issued by various international authorities, such as the Annual Reports of the Government of India, academic journals, and government websites, among others.

Constitutional Safeguards for Dalits/ Scheduled castes in India
Articles 17, 46, 15(4), 16(4A), 243D, 243T, 330, 332, 335, 338, 340 provide constitutional provisions to the Scheduled castes in India.

The Census exclusively gathers data categorized by Scheduled Castes (SCs) and Scheduled Tribes (STs). The collection of data pertaining to Other Backward Classes (OBCs) is not included in the Census. According to the 2011 Census, the total population, as well as the populations of Scheduled Castes (SCs) and Scheduled Tribes (STs), are as follows:

Table-1: 2011 Census Population

Total Population	1210854977
Total SC Population	201378372
Total ST Population	104545716

Additionally, the Census is responsible for gathering information pertaining to a range of socio-economic indicators and educational attainment. These include statistics on literacy rates, educational levels, gender distribution, employment status, primary and secondary employment, occupational classifications, and industrial categorizations of workers, among others.

The government has implemented various measures aimed at enhancing the socio-economic and educational circumstances of marginalized segments of society. These include, among other things, provisions for reservation in education and employment. An appended compilation of several welfare plans is provided, which are now being implemented to enhance the socio-economic and educational circumstances of the Scheduled Castes (SCs), Scheduled Tribes (STs), and Other Backward Classes (OBCs).

Indian Caste System's Brief History
The Indian caste system is categorized into four varnas. The hierarchical order begins with the Brahmins at the highest position, followed by the Kshatriyas, vaishyas, and Shudras. The varna system encompasses four categories, but a fifth category lies beyond its boundaries, comprising individuals referred to as "untouchables" or Dalits. These individuals are frequently assigned duties considered ritually impure and excluded from the conventional varna system. Individuals belonging to all varnas, except the Brahmins and Kshatriyas, were systematically denied equitable access to educational opportunities. Furthermore, women across all castes were unjustly robbed of their fundamental right to

pursue education. Despite implementing several governmental measures to improve the socio-economic situations of Dalits and other marginalized groups in India, these communities continue encountering numerous obstacles, persisting even in the contemporary period.

The enduring influence of the old caste system in India persists as a significant factor contributing to the social and economic marginalization experienced by the Dalit community. The Dalits, alternatively referred to as the scheduled caste or untouchables, have faced persistent deprivation of educational opportunities since the 1850s. During this decade, there was a convergence between Britain's established control over India and the significant advancements in Dalit education, primarily influenced by external factors rather than initiatives from the national government. Due to persistent adherence to established norms and behaviors, the incentives to pursue education were negligible for the Dalits, who continued to experience physical and emotional harassment. The gradual advancement of Dalit education can be attributed to the confluence of intensified endeavors to eradicate caste-based prejudice and supplementary initiatives aimed at enhancing the accessibility and attractiveness of education.

The Indian government assumed the responsibility for socioeconomic equalization upon gaining independence from British rule in 1948. Although certain benefits are associated with social initiatives and governmental measures aimed at increasing the rates of necessary education, it is important to note that the proportion of educated individuals from the Dalit community remains lower compared to the country's overall population. In Indian society, persistent challenges such as hostility, tyranny, and deficiencies in social programs continue to impede the advancement of education. In the contemporary era of the twenty-first century, the Dalit community continues to face persistent educational barriers, alongside enduring oppression, torture, and exploitation perpetrated by the upper caste demographic.

Indian society has a pronounced stratification characterized by conspicuous disparities among several socio-economic strata. The Dalits are considered the most disadvantaged group in terms of social positioning. The caste system resulted in the systematic segregation of the Dalits from the broader societal framework, depriving them of fundamental human rights necessary for their basic survival.

The status of SC's at National and Telangana state in particular.

According to the 2011 Census of India, Scheduled Caste communities are present throughout the country and constitute 16.6% of the total population. Uttar Pradesh, West Bengal, Bihar, and Tamil Nadu collectively constituted about 50% of the whole Scheduled Caste population in India, with Uttar Pradesh accounting for 21%, West Bengal for 11%, Bihar for 8%, and Tamil Nadu for 7%. The state of Punjab exhibited the highest prevalence of this phenomenon, accounting for around 32 percent of its population. Conversely, Mizoram shown the lowest prevalence, with an approximate proportion of zero. Dalits have always occupied the lowest rung of the hierarchical social system within traditional Hindu society.

Based on a report submitted to the Ministry of Minority Affairs in 2014, it was found that in 2011-12, a significant proportion of the rural population in India belonging to the Scheduled Tribe (ST) and Scheduled Caste (SC) categories, specifically 44.8 percent and 33.8 percent respectively, were residing below the poverty threshold. In the context of urban regions, it was observed that 27.3 percent of Scheduled Tribes (ST) and 21.8 percent of Scheduled Castes (SC) populations were found to be living below the poverty line. According to a government survey, there exists a disparity in economic status between Dalits and Muslims in India, with Dalits being identified as the more economically disadvantaged group.

The following is an enumeration of the initiatives undertaken by the Government of India to enhance the socio-economic and educational circumstances of the Scheduled Castes (SCs).

1. Pre-Matric Scholarship to the Children of those engaged in occupations involving cleaning and prone to health hazards
2. Post Matric Scholarship for SC
3. BabuJagjivan Ram Chhatrawas Yojana for Girls & Boys
4. National Fellowship Scheme for SC Students
5. Central Sector Scholarship of Top Class Education for SC Students
6. National Overseas Scholarship
7. Pradhan Mantri Adarsh Gram Yojana
8. Special Central Assistance to Scheduled Caste Sub Plan
9. Free Coaching Scheme for SC and OBC Students
10. Scheme of Grant in Aid to Voluntary and other organisations working for Scheduled Castes
11. Implementation of Protection of Civil Rights(PCR) Act, 1955 and the Scheduled Castes and the Scheduled Tribes (Prevention of Atrocities) {PoA} Act, 1989
12. National Scheduled Castes Finance and Development Corporation (NSFDC)
13. Assistance to State Scheduled Castes Development Corporations (SCDC)
14. Venture Capital Fund for Scheduled Castes (VCF-SC)
15. Pre-Matric Scholarship for OBC students
16. Post-Matric Scholarship for OBC students
17. Construction of Hostels for OBC Boys and Girls
18. National fellowship for OBC students
19. Dr.Ambedkar Scheme of Interest Subsidy on Educational Loan for Overseas Studies for OBCs and Economically Backward Classes(EBCs)
20. Assistance for Skill Development for OBCs/ EBCs/ DNTs
21. Venture Capital Fund for Backward Classes
22. National Backward Classes Finance and Development Corporation
23. Pre-Matric Scholarship for Scheduled Tribes students.
24. Post-Matric Scholarship for Scheduled Tribes students.
25. National Fellowship and Scholarship for Higher Education of ST Students
26. National Overseas Scholarship for Scheduled Tribe candidates
27. Supporting Projects of All India or Inter-State nature.
28. Support to Tribal Research Institutes (TRI)
29. Scheme of Centres of Excellence
30. Institutional Support for Development and Marketing of Tribal Product/Produce"
31. Tribal Festival.
32. Scheme of Grant in Aid to Voluntary Organizations working for welfare of STs
33. Minor Forest Produce (MFP) through Minimum Support Price (MSP) and Mechanism of marketing of Development of Value Chain for MFP
34. Special Central Assistance (SCA) to Tribal Sub-Scheme (TSS)
35. Development of Particularly Vulnerable Tribal Groups (PVTGs)
36. Support to National / State Scheduled Tribes Finance and Development Corporations
37. Grants under Article 275(1) of the Constitution of India.

DALIT ENTREPRENEURSHIP IN TELANGANA

Telangana, established on June 2nd, 2014, is recognized as the 29th state of the Republic of India. In order to foster entrepreneurial endeavors within the Scheduled Castes (SCs), the Government has implemented the subsequent schemes.

- "T-PRIDE - Telangana State Program for Rapid Incubation of Dalit Entrepreneurs in 2014. To encourage entrepreneurship among the Scheduled Castes (SCs) and Scheduled Tribes (STs), the Government launched a special incentive package scheme called Telangana State Program for Rapid Incubation of Dalit Entrepreneurs (T-PRIDE) in 2014.

- Allotment of Land to SC/ST Entrepreneurs by the Telangana Industrial Infrastructure Corporation: Land will be allotted to SC/ST Entrepreneurs in proportion to the SC/ST population in the State.

- TS- iPASS

- Telangana State Industrial Development and Entrepreneur Advancement (T-IDEA)

- Telangana Academy for Skill and Knowledge (TASK)

- Land allotment, acquisition and related matters."

DALIT BANDHU – ITS PROVISIONS AND FEASIBILITY

Dalita Bandhu

The Dalit Bandhu scheme in Telangana represents a social welfare initiative undertaken by the regional government to extend financial support to socioeconomically marginalized communities, particularly the Dalit population, formerly called "untouchables."

Objective of the scheme:

The main objective of the Telangana Dalit Bandhu Scheme is to give the state's Dalits more influence. Through this plan, Dalits will receive financial support to launch their own businesses. The standard of living for Dalits will rise because to this program. In addition, Dalits would become self-sufficient through using this technique. Additionally, this tactic will aid in reducing the state's unemployment rate. Under this proposal, Dalits will be able to start their own enterprises, which will promote their general development. This tactic will be used in every state assembly seat.

Some of the provisions of the scheme include:

- It is essentially a welfare program designed to support dalit families' entrepreneurship.

- The government would distribute Rs. 10 lakh to each household through this scenario.

- The country's largest cash transfer program will be this one.

- To debate this program, the Chief Minister called a meeting with the elected dalit leaders and delegates.

- During this conference, it was determined that the program would choose 11900 households, 100 from each of the 119 assembly constituencies in the state.

- Without a bank guarantee, the families would receive a monetary aid of Rs. 10 lakh to launch their businesses.

- "The government has set aside a budget of Rs 1200 crore to implement this plan."

- In the assembly seat of Huzurabad, this plan will be tested.

- This program will be gradually implemented throughout the state based on the results of its execution in Huzurabad.

- "Before drafting the rules for the programs, officials are also urged to visit the colonies and speak with the families there to get their perspectives."

- The recipients will be chosen among the eligible dalit families when the guidelines have been prepared.

- An orientation meeting for 427 Dalit men and women from the Huzurabad assembly sector was also held on July 26, 2021. This meeting included 15 resource people as well as 2 men and 2 women from each of the villages and municipal wards.

- They gave an explanation of the plan's goal.

- The pilot project for this plan will concentrate on keeping an eye on how the plan is being implemented, assessing the results, and setting up a safety fund for the recipient.

- "Along with the Rs 1200 crore, the CM also announced an additional Rs 2000 crore for the Huzurabad pilot project.

- The government will also implement a system of reservation in industries where it distributes licenses in order to encourage Dalit entrepreneurship.

- The government will provide Dalits reservations when granting permits for establishments like as wineries, pharmacies, fertilizer stores, rice mills, etc.

- To help the recipient in the event of any hardships, the government has also planned to establish a corpus that would be known as the dalit security fund forever."

- The district collector will be in charge of managing this money.

- A minimal contribution from the beneficiary is required for this fund.

- In order to track the development of the program, the government will also issue identification cards containing electronic chips.

The scheme comprises three key aspects.
- The initial factor pertains to the monitoring of plan implementation.
- The second factor involves the evaluation of the outcomes achieved.
- Another measure is establishing a security fund for the recipients, with the government and beneficiaries contributing to its formation.

The Telangana Dalit Bandhu Scheme includes establishing a permanent Dalit Security Fund, which involves the active engagement of both the government and the beneficiaries. The management of this Fund will be entrusted to the District Collectors, whom a committee including the beneficiaries will

assist. Annually, a predetermined minimum sum shall be allocated and consistently sustained to facilitate the economic empowerment and viability of the Dalit community. The proposed initiative has a budget of Rs 1200 crore to assist 11900 families throughout 119 Assembly segments.

PROBLEMS IN ITS IMPLEMENTATION AND FEASIBILITY:

The Dalit Bandhu program in Telangana, like any other welfare program, may face certain feasibility and administrative challenges in its implementation. Some of these challenges include:

Funding: The program requires a significant amount of funding to provide financial assistance to eligible Dalit families. The availability and allocation of funds may be a challenge, especially in the face of competing demands for government resources.

Eligibility: Identifying and verifying the eligibility of Dalit families for the program may be a challenge. This may involve collecting and verifying information on income, caste, and other relevant factors.

Bureaucratic delays: The process of applying for and receiving assistance under the program may be time-consuming and subject to bureaucratic delays. This may discourage some eligible families from participating in the program.

Implementation and monitoring: Effective implementation and monitoring of the program is crucial to ensure that the assistance reaches the intended beneficiaries. This may include setting up a system for receiving and processing applications, as well as monitoring the use of

These projects are still in development, so it's important to follow them carefully and look for problems when they arise. The Direct Transfer Benefits programs, like Dalit Bandhu, have their prospects and worries, just like any other program or endeavor. The Dalit Bandhu must be implemented effectively, which calls for a thorough and ongoing evaluation of the costs, advantages, and problems that may arise throughout this process and the methods used to deal with them.

The study comes to the conclusion that Dalit entrepreneurship has greatly improved the community's economic and social standing. Policymakers can create tailored initiatives to further encourage entrepreneurship among underrepresented groups by examining the elements that support and obstruct their development. In Telangana State, entrepreneurship has become recognized as a powerful tool for eradicating caste-based injustices and promoting inclusive economic growth. Future generations will definitely be motivated to free themselves from the bonds of prejudice and pave their own successful pathways as the empowerment of Dalit entrepreneurs continues.

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CHRISTIAN COMMUNITIES IN THE STATE OF ANDHRA PRADESH A SPECIAL REFERENCE TOONGOLE DISTRICT

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Mr. Clough was the agent through whom he was to accomplish it. If we were called upon to name Mr. Clough's special qualifications for the particular work to which he has been called, we should say that they were these: A capacity to common d the situation and to marshal its resources; a sound situation and an indomitable spirit. A strong love for Christ and the souls of men; a successful full-term of pioneer service in the Western States, and a strong faith both in God and in himself as God's appointed agent for the accomplishment t of a great work. We have already noted Mr. and Mrs. Clough's arrival in Nellore in 1865 and the enthusiastic manner in which they entered upon their work. It was evident from the very beginning that they had come to India for a purpose, and they burned to have it accomplished.

That purpose was to preach Christ to the Telugus. Hence it was that before Mr. Clough could speak half a dozen sentences in Telugu correctly; he began talking to the people in the streets and bazaars of Nellore. On the evening of September 12th, 1 866, Mr. and Mrs. Clough and their little boy Allen left Nellore for Ongole. After a somewhat tiresome journey, the party reached Ongole on the morning of the 17th. One of the first things a missionary wants in a new station, after a place to cover his head, is a chapel. Mr. Clough had scarcely settled in Ongole before he set to work to get a building 'that should be chapel and schoolhouse combined.

During these visits, as well as from the reports brought by the preachers, it was evident that a spirit of query prevailed in that region. Mr. Clough determined to make a visit to Tullakondapaud and the regions beyond. He intended to spend several weeks on this tour, but a little experience cession taught him that he was not prepared for it. The roads were rough, and he traveled in a bullock cart by night, halting by day to rest the bullocks. He made slow progress, of course, but it allowed him to preach in such villages as were near enough to the road to be reached on foot.

The following day, some thirty or forty people arrived, bringing with them a supply of food to last several days ran also a change of clothing to put on after they were baptized; they said they had come to learn more about Jesus, but that they believed already, and wanted to be baptized. For five days the meetings were held. At the end of the fifth day, January 20, twenty-eight converts were baptized on profession of their faith in Christ. It was a precious season that Mr. Clough will probably never forget. Mr. Clough expressed the Wish that he might spend at least six months of the year in tents, moving about the country preaching Christ.

But to do that he must be better equipped; and besides Ongole as ONGOLE. 81 the centre of operations had claims which could not be neglected. This latter consideration led Mr. Clough to renew the appeal for two more men and predicted that the time was near when the Telugus would come to Christ by thousands. This precious work of grace, while it was an inspiration to the missionaries, and doubtless caused joy in heaven, had a very different effect upon the surrounding heathen. Satan does not willingly relinquish his hold on men. No sooner had these converts abandoned his service and entered the service of the Lord than the devil put it into the hearts of his emissaries to persecute the poor Christians. Water from the public wells was denied them, false charges of crime were trumped up against them, and they were thrust into prison.

This deliverance and the addition of others from the same region rejoiced the missionaries greatly. It has been a wonder to many why it is that the Christians have come almost exclusively from the lower classes. It needs 'not have been so. Had the missionaries been disposed to pander to the caste prejudices of the Hindus as the Roman Catholics and even some Protestants do, and excluded the poor outcastes, or at all events given them a separate and lower place in the church, many caste people would no doubt have professed Christianity? But they could not do that without violating their

consciences. What a struggle it cost to take and maintain this position may be illustrated by the following incident, which took place at Ongole. In January 1867, several caste people came to Ongole, professed faith in Christianity, and asked to be baptized. But they had heard of the Madigas, who had been baptized at Tullakondapaud and objected to being in the same church with them. The missionary said they were forty miles away, and could not harm them. For a while, this seemed to pacify them. But in April, twelve more converts came from Tullakondapaud to be baptized.

The missionary almost hoped they would fail in the examination. But they gave good evidence of conversion. Here was a dilemma. Could these converts be rejected to please a heathen prejudice "The missionaries sought the counsel of God Without design on his part, Mr. Cloughturned to 1 Cor. 1 26—29: For ye see your calling, brethren, how that not many wise men after the flesh, not many mighty, not many noble, are called but God hath chosen the foolishthings of the world to confound the Wise; and God hath chosen the weak things of the worldto confound the things which are mighty and base things of the world, and things which are despised, hath God has chosen, yea, and things which are not, to bring Tol naught things which are that no flesh should glory in his presence."

In a separate room, at the same time, Mrs . Clough read this same passage, yet with no knowledge of what her husband was doing. Coming from their closets each related what hadtranspired. They had no longer any doubt as to God's will. The converts were baptized, much to the disgust of the caste people, who said: "If these are received, we cannot enter your church." This event though unpropitious, was probably one of the most fortunate circumstances in history. Finitely better that the coming in of the caste people should be delayed than that they should bring into the church a religious caste. Hence the wisdom of God in calling the poor out-castes first. When the caste people come— as come they must — it will only be when their caste has been thoroughly broken and abandoned. This will be the strongest possible evidence of the genuineness of their conversion. By the close of 1867, theOngole Church had increased from eight members at its organization to seventy-five; the newchapel was completed and paid for, almost wholly from funds collected in the country. The gospel had been preached to the people of over eight hundred villages, and over seventy thousand pages of tracts and Scripture portions had been distributed.

Besides these labors of the missionary and his assistants, Mrs. Clough had conducted a school in Ongole and frequently went out with the wives of the preachers to labor among the village women. Thus, the good seed of the kingdom was sown broadcast, and even while sowing theseed, the Lord of the harvest graciously permitted the sewers to gather in many sheaves of precious grain. But what appeared to be a shower of divine grace, was simply a few drops before a more copious rain. In his report of 1867, Mr. Clough referred to an Anglo-vernacularschool he had started, from which he had hoped for good results. But soon after, he changedhis mind and wrote to the Board that he had closed the school, dismissed his English teacher,and determined, by God's help, to be a mission army of one idea, "and devote all his energiesto raising a class of native helpers to Ongole preach Christ to the Telugus in their tongue. TheCorresponding Secretary strongly commended this course, and, quoting Mr. Clough's words,said They are very suggestive, and may well be pondered by all."

Perhaps no one pondered these words more than Mr. Clough himself, and with the result' that he long ago ceased to be the missionary of one idea that he thought he was. As far backas 1875 he started the movement which resulted in the present high school, which is precisely what he discarded in 1867. Circumstances alter cases, and the missionary who can recognizethe changed condition of the people and change his policy accordingly is wiser than he who persists on a given course irrespective of the new conditions. Mr . Clough was probably rightin discarding Anglo-vernacular schools in 1867, but not more so than in advocating them in 1875.

Abstract:
Christianity and Christian communities in Ongole in the state of Andhra Pradesh of south India and Telugu Christians have passed their stories from one generation to the next through oral traditions. These memories have sustained Telugu Christian communitiesfor over four centuries. Yet there has

been no significant attempt made to compile a comprehensive history of the Telugu Christians. Ongole is situated on the Great Northern Trunk Road, one hundred and eighty- two miles north of Madras, and ten miles from the Bay of Bengal. It is the second largest town in the Nellore District and is the headquarters of the sub-collector. Its population in 1 891 was nine thousand two hundred. Had the missionaries been disposed to pander to the caste prejudices of the Hindus as the Roman Catholics and even some Protestants do, and excluded the poor outcastes, or at all events given them a separate and lower place in the church, many caste people would no doubt have professed Christianity? But they could not do that without violating their consciences. What a struggle it cost to take and maintain this position may be illustrated by the following incident, which took place at Ongole. In January 1867, several caste people came to Ongole, professed faith in Christianity, and asked to be baptized. But they had heard of the Madigas, who had been baptized at Tullakondapaud and objected to being in the same church with them.

Christianity and Christian communities in Ongole in the state of Andhra Pradesh of south India and Telugu Christians have passed their stories from one generation to the next by oral traditions. These sustained Telugu Christian communities for over four centuries. Yet there has been no significant attempt made to compile a comprehensive history of the Telugu Christians. Ongole is situated on the Great Northern Trunk Road, one hundred and eighty- two miles north of Madras, and ten miles from the Bay of Bengal. It is the second largest town in the Nellore District and is the headquarters of the sub-collector. Its population in 1891 was nine thousand two hundred. As we trace the history of the mission at Ongole we shall find unmistakable evidence of God's wonderworking power in the great work that has been accomplished.

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LABOR RECRUITMENT SYSTEM UNDER THE BRITISHINDIA – TO SOUTH EAST ASIAN COUNTRIES (1834-1934)

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Labor migration from India began after the abolition of slavery during the early Nineteenth Century, there was a demand for a cheap, unskilled, and plant labor force. Indentured labor from India significantly filled this labor vacuum in numerous colonial settlements. During the eighty years of its existence, the system of indenture, which survived from 1830 to 1916 was responsible for the transportation of over one million Indians who provided the necessary cheap labor required for the global development of British capitalism. Indeed, the sale of southern Indian slaves by the Dutch in the latter part of the 18th century to French planters in Mauritius and Reunion was a precursor of Indenture.

Patterns of Indian emigration

Indian overseas migration was the Nialism in India and abroad, which is evident from the fact that the vast majority of Indians migrated only to the British colonies (one more exception being Surinam, then a Dutch colony). The expanding capitalist plantation economies in the overseas British colonies created a great demand for labor and other occupational groups (especially traders, artisans and government servants).

In India, a combination of the following factors led to the exodus of Indians abroad decline of the handicraft industry, increase in land revenue, famines in the second half of the nineteenth century, sluggish and enclave's industrialization and mass illiteracy Indian migration overseas began with the export of indentured, contract of "coolie" labor in the 1830s. Due to the abolition of slavery in the British Empire labor was needed to work on the sugar plantations in various British colonies until the Second World War Indians emigrated mainly as indentured or contract laborers to British Guiana, Trinidad, Surinam, South Africa, Fiji, Mauritius, Reunion (a French colony) and as Kangani or Maistry laborers to Burma, Malaysia and Sri Lanka.

Six distinctive patterns of Indian emigration can be identified:1). Indentured labor emigration
2). Kangani labor emigration
3). Maistry Labor emigration
4). "Free" or "Passage" emigration
5). ''Brain drain," or voluntary emigration6). Labor emigration to West Asia.

Indentured labor migration

Indenture was a contract by which the work for a given employer for a three to five-year term, performing the task assigned to him for a specified wage. At the end of the contract, the labor was free to re-indenture work elsewhere in the colony. After ten years he was entitled to a subsidized return passage. As already mentioned, the migration of Indian indentured labor began in 1834, ad co was officially ended in 1920. The chief importing countries of Indian labor were the West Indian Colonies, Fiji, South Africa, Mauritius Malaysia, and Ceylon.

Kangani labor migration:

Indian emigration to Ceylon was primarily in the form system of recruitment The British occupation of Kandy in 1815 and a subsequent need to build the necessary infrastructure on the island required a large workforce. This prompted the British to constitute the Pioneer Labor Force (PLF) in 1821- a semi-military organization by indenturing skilled and semi- skilled laborers from Tanjore, Trichinopoly and Madhura in South India. In the years that followed the British began to show immense interest in the coffee estates, and tea/sugar plantations. But to the unhappiness of the British, the local Sinhalese were reluctant to work on these estates and plantations and preferred agriculture and cultivation. After a decade or two, around 1837 batches of Indians began to arrive under the Kangani system of recruitmentfrom areas as shown below: -

1). Tamil-speaking districts of Madras Presidency (Trichinopoly, Tanjore, Pudukkottai, Madhura, Ramnad, Ramanathpurai Tirunelveli, Salem, North Arcot, South Arcot, Chingleput, Coimbatore, Madras arid Pondicherry)

2). Territories along Malabar Coast (Malabar, Quilon, Cochin and Trivandrum), Kanarese districts of Bangalore and Mysore and

3). Telugu districts of Chittoor, Cudappah and Vizagapatam.

3). Maistry / Contract labor migration

This form of contract labor migration was mainly to Burma from the Coastal districts in the Madras Presidency. The system is very similar to the Kangani essentially about the incentives to induce immigration, indebtedness and consequent enslavement to a middleman or broker.

* The main tenets of the system are:

1). Usually, the middlemen are the labor contractor, the head Maistry the charge mostly and the gang Maistry and the gang Maistry.

2). The Labor contractor is the man with all financial standing and influence.

3). All the agreements on the written document with thumb impression of the laborers4). Laborer is the servant of the contractor and not of the mill or firm.

5). The extent of maistry's control arid his opportunities for extortion, evident from the fact lie controlled the disbursement of wag besides being vested with an arbitrary power of selection and dismissal of laborers.

4). Free labor migration

Indian immigration to Southeast Asia also consisted of such groups of immigrants as traders, shopkeepers, entrepreneurs, salesmen, clericals, and professionals. In Malaysia, until 1957 this consists of about One - third of the total immigration. A somewhat similar situation existed in Burma, though in the case of Ceylon non-labor Indian immigration was substantially less. South Indian Chattier Hindus were the leading Indian commercial and business community in Burma and Malaysia The third form of Indian migration within the British Empire was 'passage' or 'free' emigration, or die emigration of trading castes and classes. Passage emigration was predominant in South Africa as well as the East African countries of Kenya, Tanzania and Uganda, where Gujaratis and Punjabis immigrated to East Africa following the 'opening up' of East Africa by the British and other European powers.

5. Brain Drain (or) Voluntary Emigration

The large-scale Indian immigration into the advanced industrial societies of Europe and North America began in the last sixties through the history of Indian immigration goes back to the early years of the twentieth century in North America and the Nineteenth century in Britain. The characteristic features of this type of immigration have been its voluntary nature and the migration of highly educated professionals and skilled or semi-skilled industrial workers.

6. Labor Migration to West Asia

Fifth and the final emigration pattern consist of the Indian migration to West Asia. This emigration pattern differs from the previous ones in the sense that all migrants are generally 'contract' workers and are not allowed to settle permanently in the countries of their destination. If there are any permanently settled Indian communities in West Asia, yet we do not know sociologically much about them. The labor market in West Asia is highly transitory, the skill composition as well as the volume of the Indian emigrant workforce varies from time to time. Thus, in the early 1970s, there were only about 50,000 Indians in the region.

4. Labor Recruitment System

The emigration of Indian Laborers to the for-flung British foreign colonies was not a movement of free labor. It was a regulated emigration under an agreement to labour for hire in a foreign country, which came to be termed the Indenture system. Its main principle was that the labor should serve on a plantation for a term of five years. He was entitled to a free passage home or to remain in the colony as free laborers. There were many variations of this general plan depending upon the resolutions for recruitment, and conditions during the indenture period for return and settlement. The emigration of

Indian laborers' to the sugar colonies was not for the movement of free people for battering their conditions.

It was an emigration of Indentured laborers sponsored by the planters to fill the vacuum created after the 'abolition of slavery. The number of emigrants therefore depended on the needs of the planters. In the early phase of emigration, the planters used to get laborers through Madras firms. The firms concerned, used to collect laborers from the countryside through local agents known as 'arkatis' in the north and 'maistries' in South India. The system of procuring laborers through local agents was the backbone of all recruiting operations throughout the whole period of emigration, several new methods were introduced regarding recruitment and shipment of laborers' recruitment through private companies was abolished.

An emigration agent for each colony was appointed in Madras in South India and Bombay in North India, that agent was responsible for supplying the orders of the respective colony, besides the system of licenses for emigrant ships. It was introduced to protect the interests of the emigrants to prevent abuses. Though private companies were no longer recruiting laborers on behalf of planters of the colonies, the system of inducing people from the countryside by arkatis remained in force with some modifications with the appointment of a single agent for each colony. The recruiting system streamlined than before. The agents of different colonies began to employ the arkatis to bring intending migrants from the countryside. The arkatis had advanced funds defrayed for expenses.

In the eighteenth-century seventies and eighties an extensive network of recruiting operations developed throughout the country. Greisen's report gives us a detailed account of recruiting operations. There were local and cultural depots where emigrants were accommodated before their embarkation. The local or sub-depots were also divided into two categories, large and small, each under a head recruiter. The basic recruiting operations were done by ordinary recruiters, who might be subordinate to the head recruiter of a local depot or independently dealing directly with the central depot in the port of embarkation. The officials connected with a head recruiter's depots were:

a) **The head recruiter or the sub-agent.**
b) **The recruiters**
c) **The clerk**
d) **The food contractor**
e) **The chuprassees who accompanied the recruiters to Madras and some others; who were unlicensed recruiters.**

The head recruiter was everywhere paid on the contract system. The price paid for a labourer varied according to the distance from Madras, the railway fare being the principal consideration of difference the arkatirs in north and maistries in South India consisted of all sorts of people – shop-keepers, peon, domestic servants, laborers, and even emigrants. They seldom stayed long in one agency but moved from one to another as then employment fluctuated. Only a few had visited the colonies or had any practical knowledge of them.

Mode of Recruitment

The colonial government appointed persons of approved character as emigration agents to conduct the emigration process on their behalf at the seaport and presidency towns of Madras. These agents employed experienced and responsible persons as sub-agents furnishing them with written instructions, cautioning them against malpractices, and explaining the full particulars of the colony, terms of service, description of work, climate, soil, productions and rate of wages on which they were employed to collect emigrants on the recommendation of the local sub-agent. The emigration agent nominated the recruiter. The name of the recruiter was then sent to the protector of emigrants who, if he had nothing against him, as having been dismissed or punished, granted the license.

Recruitment process

The first batch of indentured labor to Mauritius had started under the rule of Lord Bethink in 1834. At this stage there were no colonial emigration acts to control the movement of indentured laborers. Private agents, authorized by the planters of Mauritius came to India to recruit men when slavery was

formally abolished in 1834, G.C. Arbcethot, a private recruiting agent signed an agreement on September 9th, 1834, in the presence chief Magistrate, and the superintendent of the Calcutta police, this enabled him to take 36 hill coolies to Mauritius. These coolies were illiterate and they were made to affix their thumb impressions on this veryfirst contract that contained the following clauses:

1) Contract of five years 2) To and free passage

3) Rs.5 per month as ages

4) Six months of advance pay

5) Rupee 1 to be detected per month, on account of repatriation passage, if the contract to effective years were fulfilled. The entire amount totaling Rs.60 would be refunded

6) Free rations

7) Freeaccommodation8) Free clothing

With the above eight conditions in the contract, the members of the council of the East India companies were satisfied and allowed their departure. Fourteen ships sailed from Calcutta, taking indentured laborers to Mauritius. All these ships were left with good and bad workersbut no women were taken. Without women, problems on the sugar estates cropped up, where apprentice black women were already employed along with the freed black men. Governor Nicoloy (1833-40) of Mauritius insisted on better men to be recruited and women to be encouraged to migrate.

Duration of license:

No license shall be in force for a longer period than one year, and in case of misconduct on thepart of any recruiter, the protector of emigrants may cancel his license before the period of expiry for which it was granted.

License fee:

Every license shall be in the form outlined in schedule (B) to this act annexed for every license,it shall be paid to the protector a fee of ten rupees. Recruiter of labourers shall wear a badge and the concerned magistrate must countersign his license. The area medical inspector's endorsement is also compulsory to recruit labourers. Every recruiter shall be licensed to obtain labourers for some particular place to which emigration is lawful under this act, and no licenseto obtain labourers for any place shall be granted except on the application of the emigration agent of such place. Every person holding a license as a recruiter of labourers shall wear a badge bearing the following inscription in English and in the vernacular language of the town, district or districts in which he is licensed to engage laborers-recruiter of emigrants for Mauritius in any district or in the towns of Madras without having forts exhibited his license to the magistrate of such district or a magistrate of such town, and obtained the counter signature of such magistrate thereupon. The governor sent instructions to persons applying forpermission to import labor, these included:

a) The selection of real agricultural laborers

b) The recruitment of a suitable proportion of woman

c) Careful medical inspection

d) The limitation of the advance of wages

e) Careful measures for the supply of rice

The second circular adverse to employees dealt with the exact performance of contacts regarding food, clothing, punctual payment of wages, observance of hours of labour and otherpoints.

B) Recruitment of minors and child abuses

Minors illegally recruited could be claimed back by their parents if they were found missing from home. On information, parents would follow the track and reach the depots, from where they were allowed to take back their children. On 8th April 1862, it was reported to the protectorof emigrants that three minor boys were brought to the depot of Mauritius by recruiters and that one boy had his mother living in a particular village. The transfer of an Indian indentured population overseas necessitated an extensive recruitment network to mobilize labor at its source.

C) The Crossing

On the day of embarkation, emigrants were marched to the hart where these were mustered and

inspected both by the protector and the government medical inspector. The patience and stamina of the recruits were put to the test as they had to face homesickness and the strain of along sea voyage of 35 to 40 days. With the introduction of steamers in the 1860s, the voyage became shorter. Difficult conditions prevailed on board: inadequate food and water, poor accommodation and medical care as well as the harsh treatment from the shipmaster and the crew on each shipment, approximately 375 laborers were carried to the colony and specific living space was allocated to the passengers. Married couples occupied the middle of the ship;the rear section by children and women while the forward part was reserved for the larger Sardar and the crew countersigned the license. The following subsections describe the various forms of labor recruitment and the subsequent emigration of South Indians during the colonial period.

Historical background:

Labor scarcity has been a central problem, enterprises that had solved to realize an area surplus-generating potential, a fact early forgotten today in countries experiencing high employment. Any situation in the characteristics of the labor supply that threatens existing or forcible levels of accumulation can be defined as labor scarcity included in this definition are absolute shortages such as those observed in the countries today, and relative scarcities in many advanced industrialized countries. In 1860, where successful working-class organizations and Welfare state policies had strained the supply of cheap and powerless labor. Specific tendencies in industrial economies have generated specific types of labor scarcities. For example, rapid industrializations create a need for a direct, quantitative increase in the labor supply, which partly offsets labor-saving technologies. On the other hand, declining profits generate a need for cheap labor in core countries to offset the victories of organized labor.

Migration as a global labor supply system

International labor migrations did not evolve as an important labor supply system until the consolidation phase of the world capitalist economy. The earlier phase of capitalist penetration and incorporation of new regions into a single world economy under Asian/African hegemony generated different types of labor supply systems. The most important types relied on are:

a) Forced movements of people from one area of the periphery to another.

b) The subjugation of indigenous and hitherto autonomous populations and their forced transformation into laborers through such means as slavery, peonage, and indenture contract labor. Some of these persist and today are areas not completely transformed by the generalization of market relations. Colonizing migrations belong to the early stages of capitalist penetration. They are distinct from forced labor supply systems as well as from the international labor migrations that evolved at a later stage. Unlike both of these, colonizing migrations originated in developed countries and colonists were viewed as a valuable resource.

c) Although there are important differences among migrations, they have a common root in the process of capitalist penetration into previously incorporated, autonomous regions of the world that were in full motion by the 18th Century.

Overseas workers as slaves:

The abolition of slavery by the British Empire in 1834 marked the beginning of large-scale emigration from South India to Mauritius. Due to periodic famine large population of landlesslaborers and severe poverty in British India, the plantation owners of Mauritius began to employ laborers. Their primary concern was to engage cheap labor for long periods. They chose hard-working, strong, docile workers from India who were glad to escape the Tyr army of famine, poverty and oppressive landlords and tax collectors. In this situation, a new form of indentured servitude developed quickly, which was aptly described by Lord John Russell in 1840 as the new system of slavery. The plantation recruiters showed little concern or no concern towards the mental and physical well-being of slave laborers

Table: An Emigration of Indian workers to Mauritius 1848- 1858

Year	Mauritius	Year	Mauritius	Year	Mauritius
1848	5,395	1852	17,845	1856	12,635
1849	7,425	1853	12,144	1857	12,725
1850	10,030	1854	12,144 -	1858	29,946 60
1851	10,020	1855	12.916		

(Source; Reginald. T. Apple yard (Ed), International Migration Today &Volume-l, Belgium, 1988)
In the interests of migrants, government agents replaced private recruiters.

Table b- Estimated migration from Colonial India

Years	Emigrants	Returned Emigrants	Net Emigration
1834-1835	62,000	52,000	10,000
1836-1840	1,88,000	1,42,000	46,000
1841-1845	2,40,000	1,67,000	72,000
1846-1850	2,47,000	1,89,000	58,000
1851-1855	3,57,000	2,49,000	1,08,000
1856-1860	6,18,000	431,000	1,87,000
1861-1865	7,93,000	5,94,000	1,99,000
1866-1870	9,76,000	7,78,000	1,97,000
1871-1875	12,35,000	938,000	2,77,000
1876-1880	15,05,000	1233,00	2,72,000
1881-1885	15,45,000	12,08,00	337,000
1886-1900	14,61,000	12,04,00	2,56,000
1891-1895	23,26,000	1536,000	790,000
1896-1900	19,62,000	12,68,000	6,94,000
1900-1905	14,28,000	9,57,000	4,71,000
1906-1910	18,64,000	14,82,000	3,83,000
1911-1915	24,83,000	18,68,000	6,15,000
1916-1920	20,87,000	18,67,000	2,20,000
1921-1925	27,62,000	22,16,000	5,47,000
1926-1930	32,98,000	28,57,000	4,41,000
1931-1935	19,40,000	20,93,000	-1,62,000
1936-1937	8,15,000	7,55,000	59,000
Total	3,01,81,000	2,39,41,000	62,50,000 65

(Source: Reginald. AppUey3rd (Ed), International Migration Today & Volume —I, Belgium, 1988)
The introduction of stricter migration laws in labor-receiving countries strengthened the probability of short-term stays. Some countries require workers to have a college education to apply formally for a new job. The labor-exporting governments, as well as expatriate communities, are generally careful not to engage in activities, which may jeopardize their continued presence in the region, though public and private sector recruiting agents have facilitated the export of labor from South India.

Abstract

The rise in migration for employment since the mid-1834s has had serious consequences for many Asian countries. This discussion examines the issues raised by the migration abroad of thousands of skilled workers and the efforts that sending countries have made in recent years to bring the effects of labor migration more closely into line with their development objectives. It also considers several problem areas requiring the attention of policymakers and authorities responsible for the administration of overseas employment policies. It is estimated that between 1833-1937 annual labor migrant flows from the 8 major sending countries in Asia increased sevenfold, from a mere 453,700 to over 1 million. The Asian migrant workers tend to be young, male, married (with dependents in the sending country), and better educated than the average home population. Most of them come from

rural areas and are predominantly employed in construction and labor. The most distinctive feature of these workers is their concentration in a few blue-collar occupations--carpenters, masons, electricians, plumbers, lorry drivers, mechanics, and heavy equipment operators. These production and transport workers outnumber the professional and technical workers by anywhere from 3 to 1 (Philippines) to 17 to 1 (Pakistan and Sri Lanka). At the aggregate level labor emigration affects the sending country's economy through its impact on the labor market, the financial market, and the market for goods and services. It can be argued that the outflow of a significant proportion of the labor force should lead directly to a rise in labor projectivity in the sending country since capital per worker among those left behind will increase, yet it can also be argued that since migration sifts out the most skilled and experienced workers there will be an erosion of the country's human capital resources. Specific measures have been adopted in most labor-sending Asian countries to protect the welfare of migrant workers, regulate conditions of employment abroad, restrict the outflow of scarce skills, and secure new overseas markets for nationals. Despite the efforts of governments to ensure that workers have satisfactory contracts on going abroad, many cases of "contract substitution" have been reported. The present attitude of many governments toward private recruiters seems to reflect both an acknowledgement of their effectiveness in finding job placements overseas and a growing concern to regulate their activities. The present trend seems to be to allow private agencies easier access while exercising greater supervision over those permitted to operate. The impact of labor migration on the labor markets of sending countries has not been uniformly damaging, but most of the countries have adopted 1 kind of policy or another to reduce the outflow of scarce skills.

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LOST TREASURES: DOCUMENTING THE LOST DEODIS OF HYDERABAD

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Abstract:
This research project delves into the historical significance of Deodi, a distinguished mansion that served as the residence for the Nawabs of Hyderabad. Through an exploration of archival materials, historical documents, and architectural analysis, the study aims to uncover the rich cultural and traditional tapestry woven within the walls of Deodi. The research sheds light on the lifestyle of the Nawabs who inhabited this noble abode, offering insights into the broader historical context of Hyderabad. By examining the architectural features, cultural influences, and the role of Deodi in shaping the legacy of the Nawabs, this project contributes to a deeper understanding of the historical narrative surrounding Hyderabad's aristocracy. The findings presented in this research enrich our comprehension of the intricate relationships between power, architecture, and culture in the region during the era of the Nizams. The in-depth study of the Diwan deodi delves into the rich cultural heritage and marvels of the Diwan deodi. This project also sheds light on the collection of Nawab Mir Yusuf Ali Khan, Salar Jung III which holds the world record for the world's largest one-man collection. Furthermore, the study of the Rai Rayan Deodi shows the intricate fusion of three different architectural styles present in Hyderabad at the time of the Nizams. The study also sheds light on the Non-Muslim ministers of the Nizams who enjoyed all rights under Muslim rule

What Is Deodi?

In Hyderabad in the eighteenth and nineteenth centuries, the nobles and the wealthy men of the city lived in traditional fortified residences called deodis (alternately spelt as devdis, deoris or deorhis). Deodis are the traditional fortified mansions where the Jagirdars of Hyderabad lived. Jagirdars were the Nizam's officials who enjoyed the land gifted to them by the Nizam and lived off the land. Dozens of deodis with grand halls and serene courtyards held the secrets of distinct nobility. The nobles who lived in the deodis during Asaf Jahi's rule made a major contribution to the cultural life of the city. The three outstanding features of the deodis, as seen in Hyderabad, were their prominent main entrances, high enclosing walls and inner courtyards.

The basic concept of building deodis in the above-mentioned style was prevalent in Marathwada and interior Telangana for several centuries. Village chiefs and feudal lords lived in those deodis and in troubled times the deodi offered shelter not only to the feudal lord but to his people as well. These two regions were a part of Nizam's territory till the States Reorganization Act of 1956. A few typical deodis in their basic form exist to the present day in rural Maharashtra. However, the word 'deodi' seems to vary in its meaning in different languages. This can best be understood by studying the definition of the word in different languages. Dictionaries of several languages give the meaning of the word 'deodi' variously as the residence of a feudal lord, or the chief of a dargah, with the outstanding feature being the main entrance. Security seems to be the central concern for the evolution of the concept of a deodi.

- The Urdu dictionary, Farhang-e-Asafia gives the meaning of the word deodi (a Hindi word) as the residence of a Nawab or a Raja, or the chief of a dargah, with a big main entrance, big halls open spaces and separate apartments for men and women
- The standard Telugu Dictionary Shabdaratnakaramu, compiled by B. Seetharamayya identifies "deodi' as a Hindi word and gives its meaning as the entrance of a fort or that of a 'rajanagaru meaning the ruler's establishment.
- The Dictionary of Hindustani and English (1905), compiled by John Shakespeare of the East India Company identifies deodi as an Urdu word and gives the meaning as 'a threshold, a door, an antechamber or/and a porch; the doorkeeper (of such a structure) is called a 'deodidar."
- Lastly the Adarsha Marathi Shabdakosha, by Dr P.N. Joshi gives the meaning as a small platform or a niche near the front door of the house."

Emergence of Deodis In Hyderabad:

Nizam-ul-Mulk, the founder of the Asaf Jahi dynasty which lasted for two and a quarter centuries from 1724 to 1948, ruled his territory with Aurangabad, which was located in the Marathwada region, as his capital. Because of the continuous trouble between the warring factions of the Deccan, the powerful feudal lords of the region built themselves fortified residences called deodis, into which the feudal lord, as well as his people, could withdraw during troubled times. In the year 1763, Nawab Nizam Ali Khan, the second Nizam shifted his capital from Aurangabad to Hyderabad. Thereafter, the focus of political activity of the Asaf Jahis shifted to Hyderabad. For decades after the shifting of the capital, trouble with the Marathas continued right up to 1795. Consequently, the feudal lords jagirdars and nobles who moved to Hyderabad continued to build deodis as protected residences for themselves. In the later years, even after the Subsidiary Alliance was signed with the British in the year 1798, and peace prevailed, deodis continued to be built in Hyderabad.

Important jagirdars who were the close associates of the Nizam, enjoyed immense wealth and power. For them, building large and impressive deodis, lavishly decorated and serviced by retinues of well-trained servants, became a statement of power and authority. The basic structure of a deodi as it existed in rural Marathwada and Telangana was enlarged and made more elaborate in Hyderabad. The main entrance to the deodi was made more impressive and the number of courtyards within the enclosure was increased. Over some time, sundry structures like a Khazana, tosha khana, mez khana, farrash khana and bawarchi khana came to be added to the core structure, necessitated by the lifestyle of the feudal lords who, as wealthy jagirdars, led a life of luxury. The deodis of Hyderabad were like self-contained townships in which the nobles lived with their extended families and large retinues of servants. The deodis were guarded by bands of armed men, equipped with an array of weapons. Most of the deodis of the nobility of Hyderabad came to be built on similar lines with minor variations.

Architectural Layout:

Deodis were built along the important streets of the old city, and the premier nobles like the Paigahs, who were next only to the ruler in status and wealth, built their residences in Shah Gunj, a short distance from the palaces of the Nizam. The areas favoured for the homes of the other powerful nobles were the roads radiating from the Charminar. Raja Chandu Lal and Maharaja Kishen Pershad, the hereditary peshkars, and the Rai Rayans, the hereditary daftardars, had their sprawling deodis in Shah Ali Banda, close to the Panch Mahalla Palace. Diwan Deodi, the ancestral home of the Salar Jungs, was situated on the Charminar thoroughfare, on the south bank of the Musi river. The Malwalas lived on Maidan Road, close to Alijah Kotla. The deodis varied in size, some like those of the Paigahs were extensive and occupied a whole block and, at times, spilt over to the next. The deodis of the minor jagirdars were smaller and much humbler.

They were built all over the walled city, cramped and built check by jowl. In marked contrast to the present, no particular distribution pattern of residences based on religion or status (apart from those mentioned previously) can be noticed from the survey maps. There were no clusters or separate localities for the residences of either the Hindu or the Muslim nobles, they were built at random However, the Muslim deodis far outnumbered those of the Hindus There were some cases of women owning property too. Temples and mosques were built abutting the deodis. While most of the prominent deodis were on main roads, others, both important and unimportant, were in narrow alleys. Very often land was carved out to build a residence for a married son or a daughter and consequently the approach to the main deodi had to be through an alley. In the early days, there was no concept of buying land and it was granted by the ruler so that a residence could be built. Land had no market value as such, for it could be had for the mere asking in the case of those who were influential at the court.

The deodis often looked drab from the outside. From the street front, all that could be seen of a deodi was its high wall and the imposing gate. In fact, in some cases like the Diwan Deodi, shops lined the outer walls. The streets leading to the deodi were narrow, dusty and crowded. But once one entered the courtyard, it was a different world altogether. One important architectural feature that stood out in all the deodis was the large entrance. In Hyderabad, the size of the main entrance of the deodi became a symbol of the power and authority of its owner. The higher the perceived status of the lord who lived within, the larger and more elaborate the gate. Iron knobs and spikes embedded in the robust wooden gates announced the firm strength of the deodi and the tall enclosing walls gave total privacy to the residents.

The raja or the nawab would ride an elephant, which was a mark of his eminence hence the entrance to the residence had to be high enough to let an elephant and its ambari pass through it easily. The main entrance was used on special occasions, as when the master of the deodi travelled out of state or when he received high-ranking dignitaries. A small postern, inserted in the main gate, was used for the day-to-day movements of the inmates. Generally to the left but sometimes on both sides, within the main structure of the gateway itself, was provided a niche to accommodate the gatekeeper. The imposing entrances to the deodis of the premier nobles had a jillu khana, where visitors alighted and were formally received before being conducted to the presence of the lord.

On the upper floors of the entrance was the naubat khana, from where naubat played (naubat traditional music played during ceremonial occasions and sometimes to indicate the time for prayers or the time of the day); close by would be the Roshan khana, the lighting point from where, before the days of electricity, a hajjam would carry a torch and light all the lights inside the deodi Playing naubat was a privilege and an honour bestowed by the ruler on a few nobles in the city. Naubat was played thrice a day to mark the time of the day or on special occasions like the arrival of a dignitary or for an important event taking place in the deodi. In some deodis, the time of prayer was indicated. At a later point, under European influence, it became fashionable to have a clock tower placed over the main entrance. Before clock towers were introduced, cannon shots from the palace of the Nizam indicated the time.

The Grand Entrance:

One important feature that stood out in all the deodis was the large entrance, the high walls and imposing gates, the size of the main entrance of the deodi became a symbol of power and authority. Each deodi had its rhythm of life and activity, its tone set by the master of the house. The forecourt of the deodi was strictly meant for performing the official functions of the lord. The large jagirdars like the Paigahs and the Diwans not only maintained troops but also took care of the civil and judicial administration in their jagirs. They employed a large staff that operated from the push of the deodi. The peshis of the important nobles teemed with officials, followers and functionaries of all hues and stations, like the revenue officials, mansabdars, pattedars, vakils and so on. Thus, it became necessary for those nobles to maintain huge establishments for their official use Moreover, the nobles social standing in the city necessitated that they should hold court, entertain on a large scale, and hold both religious and social gatherings for the community for which they were the patroris

As such, the deodis were provided with large enclosures to hold big assemblies of courtiers, clansmen and subjects. Depending on the owner's social standing, deodis were built in varying sizes and degrees of opulence, while the basic traditional features remained the same. The deodis were provided with a series of courtyards, set apart for the public and private activities of the inmates of the house. The enclosures ranged from the public enclosures of the men to the private quarters of the family and the severely sheltered zenanas of the women Behind the deodi, close at hand, lived the huge bands of retainers and servants. One entered through the narrow and crowded alley, one could not have expected anything attractive within, but the contrast between the exterior and the interior was striking. Once past the outer office/public space, one came upon the reception area. That courtyard was provided with either a simple dalan with a takhat or a beautifully decorated elaborate dalan with rich furnishings, depending on the stature of the feudal lord. Most dalans were the reception areas where the master received formal delegations or entertained guests. A dalan was an open, pillared hall, with decorated ceilings and graceful multi-foliated arches.

The pillars of the dalans were made of either wood or stone. In the latter case, they were plastered with lime and finished into graceful fluted shapes and polished till they shone like alabaster. In front of the dalan would be a pesh-dalan, which was built opposite the main structure. A pesh-dalan was a smaller version of the main dalan, identical in every way, in its composition as well as decoration. The courtyards themselves were further appointed variously with chakras, chamans, hauzes and at a later point, marble statuary.

Interior:

The dalans were the showpieces of the deodis and were furnished opulently. In the early years, guests were seated on the floor covered by takhats, carpets or durries. The musnads, where the master of the deodi sat and held court, were grand affairs; they were covered with green or red velvet cloth (yellow being the colour of the ruler) and embroidered with intricate gold and silver threadwork called karchob. There would be an embroidered or decorated canopy over the musnad, held up with silver posts. At a

later point, with the influence of the Europeans, it became fashionable to use imported European furniture. And to decorate the deodis with European bric-a-brac.

The inner courtyards of the wealthy nobles had beautiful wooden carvings, stucco work, and painted ceilings. The exquisitely carved wooden dalans, quaintly appointed courtyards, sweet-smelling flowering bushes and the cool comfort of deep interiors - these treasures were hidden behind the high walls that enclosed the inner courtyard of the deodi. Very few of those beautiful dalans survive today. Some of the interior decorations of such chambers can be seen in the miniature paintings of Tajalli Khan and Rai Venkatachellam, who were the famous painters of Hyderabad at the time of Nizam Ali Khan (1762-1803).

The beautiful inner courtyards were used as the meeting places of the men where religious gatherings, social functions and singing and dancing sessions by nautch girls were held. Women were excluded from such gatherings, but they could watch the goings-on from the specially provided balconies overlooking the dalan, hidden behind purdahs or chilmans. In most deodis, the inner dalans had balconies and jharokhas of finely carved trellis work. Hidden from public view, the women could enjoy music or a qawwali programme. Eventually, providing jharokhas in the principal halls became such a norm in the deodis of Hyderabad that even the British Residency, built by 1806, provided balconies around the central hall for the ladies.

Chandeliers, both the hanging and the standing variety, became customary for the homes of the wealthy nobles. Commenting upon the fascination of the Hyderabadis for chandeliers, a European visitor to the city a hundred years ago wrote: The Hyderabadists are, like all natives, mad on the subject of glass chandeliers. They have them even in the mosques, and when they are tied up in muslin bags they have anything but a religious look, but rather as if the family were out of town. The chandeliers were kept covered for most of the year to protect them from dust and grime and more importantly, to keep away the birds from making nests. It was only on important occasions that they were uncovered. Deodis sometimes had their shaadi khanas meant exclusively for the use of the family. Some had places of worship, like a mosque or a deval, meant for the private use of the jagirdar and the family. The men of the family used the main entrance to the deodi while the ladies used a side entrance, called the zenani darwaza.

Zenana:

All the apartments described so far were a part of the mardana and strictly out of bounds for women. The only women that entered the men's domain freely were aged female servants, who by their closeness to the family could venture into the men's quarters carrying an occasional message or for an errand. If the women were kept out of the men's apartments, so were the men from the women's. There were separate quarters for women called zenanas, where they were left free to carry on with their activities. Only very close male members of the household were permitted into the zenanas. A passage connected the mardana to the zenana, and the entrance of the zenana was shielded further by a heavy curtain. The entrance was fiercely guarded by a trusted woman servant of advanced years called a 'mama' who blocked the entry of all men into the women's domain. On the impending entry of the occasional male visitor, she would loudly announce the name of the visitor so that the women were alerted.

Even men of the family could not get past her or enter the zenana unannounced. The mama was traditionally a loyal and old servant of the family and hence was held in high esteem in the deodi; she occupied a higher position in the hierarchy of servants and was free to enter both the men's and the women's quarters without raising a protest from either. Trusted eunuchs acted as guards and the go-betweens of the zenana and the mardana in some deodis. The provision of separate apartments for men and women zenana and mardana was adhered to strictly in the deodis of the Muslim nobles but not so in the Hindu households. In the Raja Sham raj and Malwala households, married sons and their families lived in individual apartments or suites. Zenanas had their courtyards open to the sky and were equipped with fountains, flowering bushes and pretty chamans. The atmosphere in the zenanas was restful and slow-paced.

Water dribbles in the fountains, flowering trees and plants like mynas, chameli and juhi lent fragrance to the air. Women kept birds like mynas and la munias for pleasure. Cuckoos roosted in the trees and peacocks frolicked in the bushes. All around the courtyard were rooms, skirted with verandas or dalans.

The central dalan was generally the largest and was equipped with a takhat and other paraphernalia like a hookah a silver paandan, itardan, gulab-posh, ugaldan, a khasdan and a water container, and was kept locked when not in use. Surrounded by scud silver articles of exquisite workmanship, seated on an expensive carpet or a low diwan and leaning on gau takias, the principal begum of the noble presided over the affairs of the zenana with the dignity and grandeur typical of the Hyderabadi nobility. It was customary for the women of the deodi to pay their respects to the senior begum when she held court. Guests were welcomed with itar and rose water which was sprinkled on them. The principal wives of the nobles were at times provided with separate quarters.

Members of The Deodi:

There were no hard and fast rules about the way families lived some deodis, the whole family lived in the same building, with many courtyards. The joint family concept was very much alive Women worked and lived in their enclosures while the men did their things. All the children were bundled together, they slept ate played and went to school together. Some jagirdars considered it infra dig to send their children to a school. Tutors were engaged at a high cost to teach the children in the deodi itself. Since there were restrictions on the movements of the children, they were provided with all the facilities for play and entertainment within the deodi itself. In the larger deodis like the Diwan Deodi, married daughters were provided with independent quarters in the Peshkar deodi, the wives of the peshkars ran independent establishments.

In Fakhar-Ul-Mulk's Irram Manzil palace which was built at a later period, married sons were given individual suites of rooms where they lived with their children. When the family met at one place on special occasions, they ate traditionally. A dastarkhan would be spread on the floor around which the family members sat and ate. One rule all the deodis followed was that the master and mistress of the deodi separately held court every morning in their quarters, It was customary for all the members of the family to be formally attired and to pay their respects to the head of the family. It was taboo to enter the presence of the elders if one was not appropriately dressed. In most households, the master of the deodi was addressed or referred to as 'Sarkar' by the other members of the deodi, as well as the servants. It was in the deodis that the famous Hyderabadi culture was born and nurtured. Be it the language, literature, music, dance, etiquette, courtesy, entertainment, cuisine or dress, they were all important and tradition dictated the norms.

Transgressions were frowned upon and social standing and acceptability depended on the degree of refinement that the individuals acquired. Special care was taken to teach children the finer points of etiquette right from their childhood. Behind the deodis lived the hordes of servants who worked in them. Clerks, office superintendents and the other staff lived in quarters, within easy reach of the deodi. The cooks, drivers, farrashes, ayaht, maalis, polishers, security guards and numerous other retainers lived in huge villages either close to the deodi or sometimes on the grounds of the deodi itself. In the Irram Manzil Palace, there were altogether nine hundred odd servants who lived in Wadas behind the palace. There was a marked difference between the mansions they served in and their humble dwellings.

The Baradari Addition:

An interesting addition to the deodi was the baradari, a feature unique to Hyderabad. The concept of building baradaris came down to Hyderabad from the Qutub Shahi period. The word 'baradari' literally means twelve doors. One example of a Qutub Shahi baradari is the Taramati Baradari, which still stands intact. It is built on a hillock and has a single large room, with arches on all sides to let in the breeze. It commands an impressive view of the Golconda Fort as well as the beautiful terrain all around. Baradaris were ideal resting places, best suited for use during the long summer months. Wealthy nobles like Chandu Lal and the Salar Jungs built baradaris in open spaces, beyond the city limits, away from the congestion and the noise of the city. They were set in idyllic locations, either in a garden or overlooking a water body. Chandu Lal's baradari was set in a garden, while the Salar Jungs' Lakkad Kot was situated on the banks of the Musi River. Unlike Taramati's baradari, which is a solid structure built isf stone, the baradaris of the Hyderabadi nobles were delicate double or triple-storied structures built in wood, provided with elegant jharokhas, finely carved wooden balconies and trellis work. They were meant to be the pleasure houses of wealthy men, who entertained guests lavishly with poetry, music and dance in the seclusion of these structures.

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అంతర్జాతీయ అంతర్జాల వెబినార్

తెలుగులో కేంద్ర సాహిత్య అకాడమి అవార్డు పొందిన రచనలు – సమీక్ష

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మూసీ ప్రత్యేక సంచిక

సాహిత్య సాంస్కృతిక చారిత్రక మూస పత్రిక

నిర్వహణ

తెలుగు శాఖ

మద్రాసు క్రైస్తవ కళాశాల, తాంబరం, చెన్నై

అంతర్జాతీయ సదస్సు ప్రత్యేక సంచిక

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మిలింద కథలు - సామాజిక చిత్రాలు

డా. ఉదాలి విష్ణుప్రియ, తెలుగుశాఖాధ్యక్షులు, సెంట్ ఆన్స్ మహిళా కళాశాల, మెహదీపట్నం, హైదరాబాదు

సాహితస్య భావః సాహిత్యమ్... అంటే హితంతో కూడినది, హితాన్ని చేకూర్చేది సాహిత్యం. సాహిత్యం చదివినవారు మానవునిలో మాధవుడిని చూడగలగాలి. ఏది హితం, ఎవరికి హితం అని ఆలోచిస్తే సమాజానికి హితం చేకూర్చేదే సాహిత్యం. అందుకే సాహిత్యం సమాజానికి దర్పణం వంటిది. మనిషిగా చూడదానికి, దురాచారాలను రూపుమాపటానికి, సాంఘిక శ్రేయస్సును దర్శించదానికి సాహిత్యం, సహితస్య భావః సాహిత్యం అయింది.

"సౌరభములేల చిమ్ము పుష్ప వ్రజంబు

చంద్రికలనేల వెదజల్లు చందమామ

ఎలా సలిలంబు పారు .. గాద్వేల విసరు

ఎలా నా హృదయంబు ప్రేమించు నిన్ను..."?

ఏమీ ఆశించకుండా నిర్మలంగా స్వచ్ఛంగా ఉండేదే ప్రేమ అని శ్రీ దేవులపల్లి కృష్ణకాస్త్రి అన్నారు. సాహిత్యాన్ని చదవడం పక్కన పెట్టిన సమాజం అసాంఘిక కార్యకలాపాలకు పాల్పడుతుంది. సాంకేతికంగా పలు అభివృద్ధి పథంలోకి ఎదుగుతున్న సమాజం విలువల్ని పాటించేటప్పుడు మాత్రం ఎంతో దిగజారిపోతోంది. సంఘంలోని సమస్యలను, దురాగతాలను ఎత్తి చూపించే సాధనాల్లో కథా సాహిత్యం మేటి అయినది. కథ అనేది సామాన్య పాఠకునికి దగ్గరగా ఉంటుంది.

కథా సాహిత్యానికి కొన్ని వందల ఏళ్ళ చరిత్ర ఉంది. ఒకరే కొన్ని కథలను రాసి ప్రచురిస్తే కథ సంపుటి అంటారు. అనేక మంది రాసిన కథలను ఒక పుస్తకంగా ప్రచురిస్తే దానిని కథా సంకలనం అంటారు. ఆ దిశలో రచయిత్రి మానస ఎండ్లూరి రాసిన "మిలింద" కథల సంపుటి గురించిన కొన్ని సమకాలీన అంశాలను ఈ వ్యాసం మూలంగా ప్రస్తావించడం జరిగింది. మిలింద కథాసంపుటి 2020 సంవత్సరానికి గాను కేంద్ర సాహిత్య అకాడెమీ యువ పురస్కారాన్ని అందుకుంది. 22 కథలతో పొదగబడిన ఈ కథా సంపుటిలో మన చుట్టూ పరిభ్రమించే సామజిక ఛాయలు కనిపిస్తున్నాయి. స్త్రీ స్వేచ్ఛ, ట్రాన్స్జెండర్, స్వలింగ సంపర్కులు, కులమత భేదాలు, మనుషుల మధ్య ప్రేమ... ఇలా వీటన్నితి చుట్టూ ఈ సంపుటిలోని కథావస్తువులు పాఠకుల్ని ఆకట్టుకుంటాయి.

స్త్రీ మీద జరిగే అత్యాచారాలను పలు కోణాల్లో రచయిత్రి ఈ కథల్లో స్పృశించింది. "అంతిమం" అనే కథలో మద్యం మత్తులో ఓ కొడుకు తన స్నేహితులతో కలిసి తన తల్లి పైనే అత్యాచారానికి పాల్పడిన చేదు నిజాన్ని ఈ కథ చదివిన వారెవరూ జీర్ణించుకోలేరు. కథ చివరలో ఈ నిజం తెల్సిన కొడుకు తన తల్లి చితిలోకే దూకి ఆత్మాహుతికి పాల్పడి సంఘం దృష్టిలో తల్లి ప్రేమకు నిజమైన తార్కాణంగా మిగిలిపోతాడు. "చితి మీద ఘోర అవమానంతో తల్లి ఆత్మ విలపిస్తోంది... అమ్మ ఆత్మను చూసి సత్తిబాబు ఆత్మ సిగ్గుతో చావలేక, మనిషై పారిపోలేక చావు తర్వాత అత్యాచారం లాంటి నరకాని చూసాడు..." అని తల్లి శవంతో శవమై మంటల్లో బూడిదై ఆహుతైన కొడుకు పతనాన్ని ఈ సమాజం పతనానికి నిదర్శనంగా చూపుతుంది రచయిత్రి.

ఇదే వరసలో "మెర్సీ పరిశుద్ధ పరిణయం" కథ కూడా చేరుతుంది. ఇందులో కథానాయిక మెర్సీ తక్కువ కులానికి చెందిన క్రైస్తవ స్త్రీ. అనాథ. కాలేజీ విద్యార్థిని అయిన మెర్సీని అదే కాలేజీలో పని చేసే అటెండర్ మాయమాటలు చెప్పి అత్యాచారానికి పాల్పడడం.. కానీ ఆమెని ప్రేమించిన ఆదర్శప్రాయుడైన విక్టర్ ఆమెను విశాల హృదయంతో స్వీకరిస్తాడు. "ఆ దొంగ నాయాళ్ళు తక్కువ కులమని మనల్ని దూరం పెడతారు. మన ఆడవాళ్ళని ఉంచుకున్నప్పుడు, పాడు చేసేటప్పుడు మాత్రం అంటరానితనం పని చెయ్యదు. వాళ్ళ ఆడబిడ్డల్ని కన్నెత్తి చూసినా గుడ్లు పీకి నాలుకలు తెగ్గోస్తారు. మన మీద ఎన్ని దాడులు జరిగినా క్షమాగుణం కలిగి ఉండమనే మతం మనది. మన చట్టాలు కూడా మనకి ఆ విషయంలో ఎంతో సాయం చేస్తాయి. ప్రేమించిన పిల్లకి అఘాయిత్యం జరిగితే వదిలేసేటంత దగులబాజీవి కాదు మెర్సీ.." అని ఆమెని విక్టర్ వివాహం చేసుకుంటాడు. ఈ కథలో దేహానికి గాయమైంది కానీ మనసుకు కాదు అని రచయిత్రి విక్టర్ పాత్ర ద్వారా సమాజానికి సందేశం ఇస్తుంది.

భార్యని పని చేసే యంత్రంగా భావించే భర్తల మనస్తత్వాన్ని సూదిగా వ్యక్తీకరించిన మరో కథ కుసుమం.. "అవిటి పెనిమిటి". ఇందులో ప్రధాన పాత్ర పనిమనిషి దుర్గ. అభ్యుదయ భావాలకు ప్రతీకగా ఈ పాత్రని మలిచిన తీరు ఆకట్టుకుంటుంది. పురుషాధిక్యతను ప్రదర్శించే పాత్ర విష్ణు. దుర్గ భర్త పోలియోతో కాళ్ళు చచ్చుబడినా భార్యకు చేదోడు వాదోడుగా అన్ని పనులు చేసి పెడుతుంటాడు. ఎంతో ప్రేమగా ఉంటాడు. కానీ విష్ణు భార్య పద్మావతి చదువుకుని ఉద్యోగం చేస్తున్నా భర్త చేతి ఊతకర్రలా ఉంటుంది. ఈమె భర్త ఎత్తిన గ్లాసు కింద పెట్టని పురుషాహంకారి. పద్మావతికి నలతగా ఉన్నా ఆమెకి చిన్న సాయం చేయకపోగా, దుర్గ లాంటి వారు సాయం చెయ్యబోయినా వారిస్తాడు. అతన్ని ఎదిరించి పల్లెత్తు మాట అనడానికి పద్మావతి వెనుకాడినా.. పని మనిషి దుర్గ మాత్రం అతని దౌష్ట్యాన్ని చూస్తూ మౌనంగా ఉండిపోలేదు. ఆమె ఈ తరం స్త్రీలకి ప్రతీకగా గొంతు విప్పింది. విష్ణు అవితితనాన్ని ఎత్తి చూపింది. నీలాంటి వాడి దగ్గర పని చెయ్యనంటూ అతన్ని దులిపేస్తుంది. పని వదిలేసి వెళ్ళిపోతుంది. ఈ సందర్భంగా రచయిత్రి "జీతం తీసుకునే పని మనోచ్ఛైనా సెలవు పెడుతుందేమో గానీ, ఉద్యోగం చేస్తూ వంట మనిషిగా స్థిరపడ్డ భార్యకి సెలవు పెట్టే అవకాశం ఉంటుందా..?" అని ప్రశ్నిస్తుంది. "ఆఫీసుకు వెళ్ళేటప్పుడు చెప్పులేసుకోవడానికి, భర్తకి వెళ్ళొస్తానని చెప్పడానికి పెద్ద తేడా ఉండదు. రెండూ అనుమతుల్లేకుండా యాంత్రికంగా చేసే పనులే.." అంటుంది. నవ సమాజంలో స్త్రీ యాంత్రిక జీవితానికి నిలువుటద్దాలు ఈ వాక్యాలు!

స్త్రీలు పెట్టుకునే బొట్టును కథ వస్తువుగా తీసుకుని పలు కోణాల్లో చర్చించిన వైనం మనల్ని కట్టిపడేస్తుంది. "బొట్టు" అనే కథలో హిందువైన ప్రిన్సిపాల్ తన వద్దకు వచ్చిన బొట్టు లేని క్రైస్తవ విద్యార్థిని ఆశాజ్యోతికి కాలేజీ సీటుని నిరాకరిస్తుంది. రచయిత్రి ఈ కథకు ముక్తాయింపునిస్తూ.. "ఆశాజ్యోతి ఆశలు అడియాసలై ఆమె నుదుటి మీద లేని కుంకుమబొట్టు కళ్ళల్లోంచి కన్నీటి బొట్టి రాలింది. వాళ్ళు వెనుదిరగగానే ప్రిన్సిపాల్ కామాక్షి గబా గబా ఫోన్ ఆన్ చేసి కాంటాక్ట్ లిస్ట్ తీసి 'జి' కేటగిరీలో 'గరికపాటి' అనే నెంబర్ని డిలీట్ చేసింది. అతన్ని కలిసిన రెండు సార్లు మోహనికి బొట్టెందుకు లేదో ఇప్పుడర్థమైంది. ఈ గరికపాటి ఆమె అనుకున్న 'ఘనాపాటి' కాదని..! అని కథని ముగిస్తుంది.

ఇక ఇంటి నుంచి తన చిన్నారి కుక్కపిల్లతో బాటు తప్పిపోయిన పిల్లకి ఆశ్రయమిచ్చినా, ఆ ఇచ్చిన వారు తమ మతం కాదని తెలిసి కనీసం థాంక్స్ కూడా చెప్పుకుండా వెళ్ళిపోయే కుహనా మనస్తత్వం పోకడల్ని "బొట్టు కుక్క" కథలో చూస్తాం! "కుక్కపిల్ల నా కళ్ళలోకి చూస్తోంది.. నేను దాని బొట్టువైపు చూసాను. మతమే కాదు ఇప్పుడు కులం కూడా తెలిసింది. కమ్మారి అమ్మాయి వెంట వచ్చిన కుక్కపిల్ల. దాని జాతి కుక్కల్ని అది గుర్తు పడుతుందేమో. పాపం మనుషులే వారి వారి జాతుల్ని ఇప్పటికీ చెప్తే గానీ గుర్తు పట్టలేకపోతున్నారు!!" అని మత పిచ్చి పట్టిన వారికి ఈ రచయిత్రి గడ్డి పెడుతుంది.

ఈ కథలకు సంబంధించిన సమీక్షల్లో సైతం ఈ కులాన్ని, మతాన్ని ప్రజలు గుడ్డిగా ఎందుకు అనుసరిస్తారనే విషయాన్ని గమనిస్తే పలు ఆసక్తికరమైన అంశాలు వెల్లడవుతాయి. హిందువుల్లో అత్యధిక సంఖ్యాకులు వర్ణాంతర భోజనాలకు వర్ణాంతర

వివాహాలకు అంగీకరించరెందువల్ల? ఈ ప్రశ్నకు జవాబు ఒక్కటే. హిందువులు పవిత్రంగా ఎంచుకునే సిద్ధాంతాలకు విశ్వాసాలకున్న వర్ణాంతర భోజనాలకు వర్ణాంతర వివాహలకున్నా, పొసగదు. కులమనేది హిందువులను కలవకుండా చేసే ఒక ఇటుక గోడో, మూల్య తోవో కాదు. సులభంగా తొలగించి పారవేయడానికి! హిందువులలో కులం అనేది ఒక భావం. ఒక విశ్వాసం. ఒక మనస్థితి. కులాన్ని తొలగించడం అంటే భౌతికమైన ఒక అడ్డంకిని తొలగించడం కాదు. మనోభావనలోనే ఒక మార్పును సాధించడం. కులం చెడ్డదే కావచ్చు. మానవుడు మరో మానవుడి పట్ల అమానుషంగా ప్రవర్తించేంతటి దుష్ప్రవర్తనకు కారణం కులమే కావచ్చు. అయితే ఒక సత్యాన్ని మనం గుర్తించవలసి ఉంది. హిందువులు కులం పట్ల అంత పట్టుదలగా ఉంటారంటే అందుకు కారణం వాళ్ళు అమానుష ప్రవృత్తి కలవారా, తల తిరుగుడు మనుషుల్లో కావడం కాదు. వీళ్ళు కులాన్ని పట్టుకుని అంతగా వేలాడుతారంటే వాళ్ళు పూర్తిగా మతం అంటే పిచ్చి నమ్మకం కలవాళ్ళు కనక. హిందూ ప్రజలు కులమంటే పట్టింపు కలిగి ఉండడం కాదు. నిజానికి నా ఉద్దేశంలో అసలు తప్పు ఏదంటే అది వాళ్ళ మతం. కులం అనే పిచ్చి నమ్మకాని వాళ్ళ మనసులో నాటిన వాళ్ళ మతం. అటువంటప్పుడు మనం ఎదుర్కోవాల్సిన వస్తువు కుల వ్యవస్థను అనుసరిస్తున్న ప్రజలది కాదు. అట్టి కుల వ్యవస్థతో కూడిన మతాన్ని వాళ్ళకు ప్రబోధిస్తున్న శాస్త్రాలు. అందువల్ల వర్ణాంతర భోజనాలకు, వర్ణాంతర వివాహలకు వ్యతికేకులైన వారిని విమర్శించడం వల్ల కానీ, హేళన చేయడం వారనంతర భోజనాలు, అక్కడక్కడా వర్ణాంతర వివాహలు జరపడం వల్ల కానీ ఏమీ ప్రయోజనం ఉండదు. మనం అనుసరించవలసిన సరైన మార్గం ఏమిటంటే శాస్త్రాల పట్ల, వాటి పవిత్రత పట్ల ప్రజలకు గల విశ్వాసాన్ని తొలగించడం! ఇదే సంపుటిలోని "బొట్టు భోజనాలు" కథలో మానస అనే పాత్ర కులం నుంచి మత ప్రాంగణంలోకి అడుగు పెట్టింది. మార్గం ఆమెకు కనపడింది. ఆ మార్గంలో వేగంగా ప్రయాణం చేయగలదని నమ్మకం ఈ కథలు కలిగిస్తున్నాయన్నది ఈ కథల్ని సమీక్షించిన ప్రముఖ స్త్రీవాద రచయిత్రి ఓల్గా అభిప్రాయం!

        ఇద్దరు వ్యక్తుల మధ్య ప్రేమ చిగురించడానికి వారిద్దరూ ఆడ, మగ కావాల్సిన అవసరం లేదన్న అంశాని "అదే ప్రేమ" కథలో ఉటంకిస్తారు. స్వలింగ సంపర్కాన్ని కొన్ని దేశాల్లో నిషేధించినా ప్రపంచంలో సింహభాగం దీనిని చట్టబద్ధం చేసాయి. ఈ కథ వస్తువుతో అర్జున్, గోపాల్ అనే ఇద్దరు మగవారి మధ్య ఏర్పడిన ప్రేమని అందంగా వర్ణిస్తారు రచయిత్రి. కథ చివరి వరకు వీరి మధ్య సంభాషణని ఓ అబ్బాయి, ఓ అమ్మాయి మాట్లాడుకుంటున్నట్టుగానే నడిపిస్తూ.. ముగింపుల్లో చిన్న కొసమెరుపుల వాళ్ళిద్దరూ అబ్బాయిలేనని పేర్కొనడం ఆసక్తిదాయకం. విశ్వవ్యాప్తంగా మారుతున్న మానవ సంబంధాలను స్వతహోగా ఒక స్త్రీ అయినా సాహసోపేతంగా తన కథకు వస్తువుగా ఎంచుకోవడం గమనార్హం!

        "మైదానంలో నేను" అనే కథలో భార్య భర్తల మధ్య మనసులు ఇచ్చిపుచ్చుకుంటేనే వారి బంధం కలకాలం నిలుస్తుందనే వాదనకి కొన్ని చేర్పులు చేస్తూ వారి మధ్య శారీరక సంబంధం కూడా వారి బంధాన్ని దృఢ పరచడంలో కీలక పాత్ర వహిస్తుందనే విషయాని రచయిత్రి ఈ కథలో పేర్కంటారు. కథానాయిక తన భర్త చలం నవల "మైదానం"లో కథానాయకుడు అమీర్ లాగా ఉండాలని ఆశ పడుతుంది. మొదట్లో పెళ్ళైన వారి కాపురం సినిమాల్లో చూపించే విధంగా ఉంటాయని కలలు కంటుంది. అలాగే నవలా నాయికల జీవితంలాగే తన జీవితం కూడా ఉంటుందని అనుకుంటుంది. ఆ దిశలోనే మైదానం నాయకుడి పాత్రలో తన భర్తని ఊహించుకుంటుంది. కానీ దానికి విరుద్ధంగా అతని ప్రవర్తన ఉండడం చూసి నిరాశ పడుతుంది. ఒక దశలో ఆ విషయం అతనికి వివరించడమే కాదు. ఆ మైదానం నవలని ఆసాంతం చదివి వినిపిస్తుంది. చివరికి ఆమె భర్త తన అంతర్యం గ్రహించాక తాను ఇన్నాళ్లు కోల్పోయింది ఏమిటన్నది తెలుస్తుంది. "నువ్వు చదివి వినిపించిన మైదానం నవల అర్థం చేసుకోవడానికి నేను సొంతంగా మళ్ళీ మళ్ళీ చదువుకున్నాను. ప్రేమను బైట పెట్టడం ఎంత అవసరమో తెలుసుకున్నాను. ఇన్నాళ్లు నేను ప్రదర్శించిన పశుకామానికి సిగ్గు పడుతున్నాను. క్షమించు.. నీ జీవితంలో నేనొక ప్లీడర్ మొగుడిగా కాక అమీర్‌గా మిగిలిపోవాలని నిర్ణయించుకున్నాను.." అనడం ముక్తాయింపు!

మనం మర్చిపోయిన, నిర్లక్ష్యం చేసిన ఎన్నో జీవితాలను ఈ కథలు వెలుగులోకి తెచ్చాయని చెప్పొచ్చు. కథలు ఇలాగే రాయాలి, ఇలాగే ఉండాలని గిరి గీసుకున్న ఒక సంప్రదాయానికి ఈ మిఖింద కథా సంపుటి తిలోదకాలిచ్చింది. కాలం ఒక్కో సమయానికి ఒక్కొక్కరిని ఎన్నుకుంటుంది.. ఈ కాలపు కొన్ని కథలు చెప్పడానికి ఎన్నుకోబడిన రచయిత్రి మానస ఎండ్లూరి. కేవలం ఆడ, మగ అనే వర్గాల్ని మాత్రమే గుర్తించే సమాజంలో స్వలింగ సంపర్కుల్ని, ట్రాన్స్జెండర్ల జీవితాల్ని అద్భుతంగా ధైర్యంగా అక్షరీకరించిన కలం ఈ రచయిత్రిది. ఇది ఈ తరం కథా సంపుటి. వెలుగు రేఖలు ప్రసరించని ఎన్నో జీవితాలపై ఎత్తి పట్టిన దివిటీ!

ఉపయుక్త గ్రంథ సూచి

1. మిఖింద – మానస ఎండ్లూరి
2. కృష్ణపక్షము – శ్రీ దేవులపల్లి కృష్ణశాస్త్రి.

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CHRISTIAN COMMUNITIES IN THE STATE OF ANDHRA PRADESH A SPECIAL REFERENCE TOONGOLE DISTRICT

Dr Martha Sreenivas, Lecturer In History

Mr. Clough was the agent through whom he was to accomplish it. If we were called upon to name Mr. Clough's special qualifications for the particular work to which he has been called, we should say that they were these: A capacity to common d the situation and to marshal its resources; a sound situation and an indomitable spirit. A strong love for Christ and the souls of men; a successful full-term of pioneer service in the Western States, and a strong faith both in God and in himself as God's appointed agent for the accomplishment t of a great work. We have already noted Mr. and Mrs. Clough's arrival in Nellore in 1865 and the enthusiastic manner in which they entered upon their work. It was evident from the very beginning that they had come to India for a purpose, and they burned to have it accomplished.

That purpose was to preach Christ to the Telugus. Hence it was that before Mr. Clough could speak half a dozen sentences in Telugu correctly; he began talking to the people in the streets and bazaars of Nellore. On the evening of September 12th, 1 866, Mr. and Mrs. Clough and their little boy Allen left Nellore for Ongole. After a somewhat tiresome journey, the party reached Ongole on the morning of the 17th. One of the first things a missionary wants in a new station, after a place to cover his head, is a chapel. Mr. Clough had scarcely settled in Ongole before he set to work to get a building 'that should be chapel and schoolhouse combined.

During these visits, as well as from the reports brought by the preachers, it was evident that a spirit of query prevailed in that region. Mr. Clough determined to make a visit to Tullakondapaud and the regions beyond. He intended to spend several weeks on this tour, but a little experience cession taught him that he was not prepared for it. The roads were rough, and he traveled in a bullock cart by night, halting by day to rest the bullocks. He made slow progress, of course, but it allowed him to preach in such villages as were near enough to the road to be reached on foot.

The following day, some thirty or forty people arrived, bringing with them a supply of food to last several days ran also a change of clothing to put on after they were baptized; they said they had come to learn more about Jesus, but that they believed already, and wanted to be baptized. For five days the meetings were held. At the end of the fifth day, January 20, twenty-eight converts were baptized on profession of their faith in Christ. It was a precious season that Mr. Clough will probably never forget. Mr. Clough expressed the Wish that he might spend at least six months of the year in tents, moving about the country preaching Christ.

But to do that he must be better equipped; and besides Ongole as ONGOLE. 81 the centre of operations had claims which could not be neglected. This latter consideration led Mr. Clough to renew the appeal for two more men and predicted that the time was near when the Telugus would come to Christ by thousands. This precious work of grace, while it was an inspiration to the missionaries, and doubtless caused joy in heaven, had a very different effect upon the surrounding heathen. Satan does not willingly relinquish his hold on men. No sooner had these converts abandoned his service and entered the service of the Lord than the devil put it into the hearts of his emissaries to persecute the poor Christians. Water from the public wells was denied them, false charges of crime were trumped up against them, and they were thrust into prison.

This deliverance and the addition of others from the same region rejoiced the missionaries greatly. It has been a wonder to many why it is that the Christians have come almost exclusively from the lower classes. It needs 'not have been so. Had the missionaries been disposed to pander to the caste prejudices of the Hindus as the Roman Catholics and even some Protestants do, and excluded the poor outcastes, or at all events given them a separate and lower place in the church, many caste people would no doubt have professed Christianity? But they could not do that without violating their

consciences. What a struggle it cost to take and maintain this position may be illustrated by the following incident, which took place at Ongole. In January 1867, several caste people came to Ongole, professed faith in Christianity, and asked to be baptized. But they had heard of the Madigas, who had been baptized at Tullakondapaud and objected to being in the same church with them. The missionary said they were forty miles away, and could not harm them. For a while, this seemed to pacify them. But in April, twelve more converts came from Tullakondapaud to be baptized.

The missionary almost hoped they would fail in the examination. But they gave good evidence of conversion. Here was a dilemma. Could these converts be rejected to please a heathen prejudice "The missionaries sought the counsel of God Without design on his part, Mr. Cloughturned to 1 Cor. 1 26—29: For ye see your calling, brethren, how that not many wise men after the flesh, not many mighty, not many noble, are called but God hath chosen the foolishthings of the world to confound the Wise; and God hath chosen the weak things of the worldto confound the things which are mighty and base things of the world, and things which are despised, hath God has chosen, yea, and things which are not, to bring Tol naught things which are that no flesh should glory in his presence."

In a separate room, at the same time, Mrs . Clough read this same passage, yet with no knowledge of what her husband was doing. Coming from their closets each related what hadtranspired. They had no longer any doubt as to God's will. The converts were baptized, much to the disgust of the caste people, who said: "If these are received, we cannot enter your church." This event though unpropitious, was probably one of the most fortunate circumstances in history. Finitely better that the coming in of the caste people should be delayed than that they should bring into the church a religious caste. Hence the wisdom of God in calling the poor out-castes first. When the caste people come— as come they must — it will only be when their caste has been thoroughly broken and abandoned. This will be the strongest possible evidence of the genuineness of their conversion. By the close of 1867, theOngole Church had increased from eight members at its organization to seventy-five; the new chapel was completed and paid for, almost wholly from funds collected in the country. The gospel had been preached to the people of over eight hundred villages, and over seventy thousand pages of tracts and Scripture portions had been distributed.

Besides these labors of the missionary and his assistants, Mrs. Clough had conducted a school in Ongole and frequently went out with the wives of the preachers to labor among the village women. Thus, the good seed of the kingdom was sown broadcast, and even while sowing theseed, the Lord of the harvest graciously permitted the sewers to gather in many sheaves of precious grain. But what appeared to be a shower of divine grace, was simply a few drops before a more copious rain. In his report of 1867, Mr. Clough referred to an Anglo-vernacularschool he had started, from which he had hoped for good results. But soon after, he changedhis mind and wrote to the Board that he had closed the school, dismissed his English teacher,and determined, by God's help, to be a mission army of one idea, "and devote all his energiesto raising a class of native helpers to Ongole preach Christ to the Telugus in their tongue. TheCorresponding Secretary strongly commended this course, and, quoting Mr. Clough's words,said They are very suggestive, and may well be pondered by all."

Perhaps no one pondered these words more than Mr. Clough himself, and with the result' that he long ago ceased to be the missionary of one idea that he thought he was. As far backas 1875 he started the movement which resulted in the present high school, which is precisely what he discarded in 1867. Circumstances alter cases, and the missionary who can recognizethe changed condition of the people and change his policy accordingly is wiser than he who persists on a given course irrespective of the new conditions. Mr . Clough was probably rightin discarding Anglo-vernacular schools in 1867, but not more so than in advocating them in 1875.

Abstract:

Christianity and Christian communities in Ongole in the state of Andhra Pradesh of south India and Telugu Christians have passed their stories from one generation to the next through oral traditions. These memories have sustained Telugu Christian communities for over four centuries. Yet there has

been no significant attempt made to compile a comprehensive history of the Telugu Christians. Ongole is situated on the Great Northern Trunk Road, one hundred and eighty- two miles north of Madras, and ten miles from the Bay of Bengal. It is the second largest town in the Nellore District and is the headquarters of the sub-collector. Its population in 1 891 was nine thousand two hundred. Had the missionaries been disposed to pander to the caste prejudices of the Hindus as the Roman Catholics and even some Protestants do, and excluded the poor outcastes, or at all events given them a separate and lower place in the church, many caste people would no doubt have professed Christianity? But they could not do that without violating their consciences. What a struggle it cost to take and maintain this position may be illustrated by the following incident, which took place at Ongole. In January 1867, several caste people came to Ongole, professed faith in Christianity, and asked to be baptized. But they had heard of the Madigas, who had been baptized at Tullakondapaud and objected to being in the same church with them.

Christianity and Christian communities in Ongole in the state of Andhra Pradesh of south India and Telugu Christians have passed their stories from one generation to the next by oral traditions. These sustained Telugu Christian communities for over four centuries. Yet there has been no significant attempt made to compile a comprehensive history of the Telugu Christians. Ongole is situated on the Great Northern Trunk Road, one hundred and eighty- two miles north of Madras, and ten miles from the Bay of Bengal. It is the second largest town in the Nellore District and is the headquarters of the sub-collector. Its population in 1891 was nine thousand two hundred. As we trace the history of the mission at Ongole we shall find unmistakable evidence of God's wonderworking power in the great work that has been accomplished.

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Research Article

"Navigating The Ai Frontier: A Study Of Ai Integration In It Employee Training And Development"

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ARTICLE INFO	ABSTRACT
	This empirical study investigates the effects of integrating Artificial Intelligence (AI) into training and development (T&D) programs for Information Technology (IT) employees. With a sample of 100 respondents drawn from diverse IT backgrounds, the study aims to provide insights into the perceived benefits, challenges, and overall effectiveness of AI-driven T&D initiatives. The findings reveal several significant impacts of AI integration in T&D for IT professionals. Firstly, respondents report a notable improvement in the efficiency and effectiveness of learning experiences facilitated by AI-powered platforms. Personalization features such as adaptive learning algorithms and real-time feedback mechanisms are highlighted as key contributors to enhancing engagement and knowledge retention among employees. Additionally, the integration of AI-driven simulations and virtual reality technologies is found to promote experiential learning, enabling employees to develop practical skills in a simulated environment. Despite the positive outcomes, the study identifies several challenges associated with AI integration in T&D. Concerns regarding data privacy and security emerge as prominent issues, with respondents expressing apprehensions about the collection and usage of personal information within AI-driven systems. Moreover, the initial investment required for implementing AI technologies poses financial constraints for some organizations, limiting their ability to fully leverage the potential benefits of AI in T&D initiatives. The study concludes with recommendations for optimizing the integration of AI in T&D programs for IT employees. Strategies for addressing privacy concerns through transparent data governance frameworks and compliance with regulatory standards are emphasized. Furthermore, the importance of providing adequate training and support to employees to navigate AI-driven platforms effectively is underscored. By addressing these challenges and capitalizing on the opportunities presented by AI, organizations can enhance the learning and development outcomes for IT professionals, thereby fostering a skilled workforce capable of thriving in the rapidly evolving digital landscape.

Keywords: Artificial Intelligence, Training and Development, IT Employees, Integration, Knowledge |

1. INTRODUCTION OF THE STUDY:

AI is changing everything, including vocations and professional activities. This research examines how AI may affect education and worker education. Artificial intelligence is in most industries. Access to AI technologies and apps in the workplace is growing. AI has the ability to change how firms identify, recruit, and train new hires, as well as assess and explore professional development prospects. Therefore, we may pass on our knowledge and experience to future generations. AI-driven solutions may analyse current data and deliver insights for efficiency improvement. Artificial intelligence is transforming employee recruiting and engagement in human resources and professional development. Companies in the $130 billion US

corporate training market may employ AI to better specialised training and analyse learning patterns using predictive analytics. Academics and business executives believe that AI is best. With these elements, AI is here today, not in the future. Example: your email service. This AI-powered system filters emails to avoid spam. Amazon uses AI to recommend items based on user data. Google Assistant, Siri, and Alexa improve user experience using AI. Although AI is still young, several corporations have invested extensively in the technology, expecting big things from AI-powered goods.

2. SIGNIFICANCE OF THE STUDY:

AI has impacted everything and will affect human learning and development for decades. Recent AI advances allow users to try several information-gathering methods. AI in the classroom has transformed student engagement with course content. This technical development is one of the most significant since 2018. AI has impacted every facet of human existence, from social media and business to coding and combat. Because humans and AI are so intertwined, contemporary life would be impossible without computers. AI has made learning and development more efficient and easier. Global education relies on online courses and resources to help individuals learn and develop professionally and personally. Learning and development experts must stay up with technology advances to boost learning. Learning and development experts may research and apply emerging AI technologies to build unique teaching techniques. Gartner expects that by 2020, bots will handle 85% of customer assistance, surpassing human operators. Another research estimated that AI would supply 20% of training resources. According to Bank of America, AI will fuel $14–$33 trillion in yearly economic growth by 2025. This research focused on IT firm training and career development using AI. Two well-known AI-heavy firms are under scrutiny. Large IT companies often utilise AI because they invest in their staff' skills to stay up with global advances and provide them to their customers.

3. STATEMENT OF THE PROBLEM

Eric Premnath and Arun Antony Chully (2019) say AI's rapid advancement is changing business and career growth. This article discusses AI's integration on training & Development. Nowadays, you can't go far without hearing about AI. More AI-powered goods and services are appearing in workplaces. AI will definitely change how we acquire new skills, grow in our jobs, and get employed, on-boarded, and launched into organisations. This will be the platform for teaching future workers. In 2017, Sandeep Gandhi Organisational leaders struggle with the lack of customised learning, despite technology's transformation of training and development in the recent decade. Learning and development professionals typically condemn generic and non-tailored learning experiences for urgent skills training and staff training courses. Material manufacturing time may be related to this situation. Employees may struggle to navigate and adapt to most Learning Management Systems (LMSs)' sophisticated user interfaces. Finding and using relevant learning materials is tough, affecting User Experience.

4. LITERATURE – REVIEW:

Kalia and Mishra (2023[1]) understand how AI affects numerous HR operations in 2023. The research found that AI improves efficiency across several HR functional categories. The study's major result is that HR departments employ AI for dull and repetitive duties. AI and ML offer many commercial advantages, but few organisations are using them. The results show that contextual variables impact an organization's AI adoption. Pan and Froese (2022[2]) believe AI will transform HR when fully evolved. Researchers conducted a systematic literature review (SLR) to analyse 184 AI in HRM papers. The research found that various studies concentrate on different topics and use different methods. This large literature analysis revealed that most research on this issue were theoretically sound. Researchers should include persons from different HR backgrounds in future studies, according to the authors.

According to Herrmann (2022[3]), many AI terms are confusing. This is why the writers thoroughly studied relevant literature. The Euler diagram was used to build a common language for AI researchers. Machine learning is an area of data science. Since this analysis only includes Scopus-indexed peer-reviewed publications, conference papers, books, and reports are excluded. Chilunjika et al. (2022[4]) investigated how South African public sector organisations use AI in HRM. The writers critically analyse the relevant literature, focusing on its essential points and arguments. The study found that AI eliminates boring operations, freeing up South African HR experts to concentrate on strategic management. AI helps government agencies hire and choose without bias.

Using current data, Gambhir et al. (2022[5]) shown that deep learning can find patterns in big datasets with unparalleled analytical abilities. These tools are used extensively in marketing. It helped marketers identify customer wants. Marketing analytics and HRM were shown to assess workers' competencies and build industry-specific training programmes. AI can automate laborious, time-consuming activities and help HR make decisions. Gurusinghe et al. (2021[6]) report that HR analytics are being used to guide strategic and

operational choices. HR analytics aims to get a competitive advantage. The research provides a theoretical framework for understanding HR analytics adoption drivers and predicted HR analytics impacts. The company's environment affects HR analytics, highlighting contextual aspects. Organisational learning level may mitigate the influence of other factors on PHRA competence improvement, the research found.

Del Giudice et al. (2021[7]) examined how AI affects human resource management. Artificial intelligence and human resource management may expedite sustainable development, according to the authors' theoretical approach. AI will improve human abilities, said the authors. Kambur and Akar (2021[8]) sought to measure human resource managers' AI competence and develop a reliable evaluation instrument. Turkish HR managers and workers provided 821 replies for the survey. The research supports participants' opinions that technology may simplify repetitive tasks, make finding suitable applicants easier, and increase businesses' talent access. According to our comments, AI in training and development may reduce training time and HR involvement.

Although research has examined how training improves employee work satisfaction, Nauman et al. (2021[9]) notes that many questions remain. This research examined whether training increases organisational loyalty and productivity and work satisfaction. The conclusion reached by 219 participants supported the theory. Workplace training makes employees happy. Training promotes staff loyalty and productivity. A worker's satisfaction increases with job performance. Training boosts morale and business loyalty, which boosts productivity. More economic sectors, including service and manufacturing, should be studied to confirm this link. Votto, A. M., Valecha, R., Rad, P., & Rao, H. R. (2021[10]).) analysed this trend. The study teaches researchers, educators, and policymakers AR learning methodologies, goals, competency levels, and abilities. Augmented Reality professionals are in demand owing to the technology's rapid ascent and varied applications.

5. OBJECTIVES OF PRESENT STUDY:
❖ To evaluate AI integration in IT employees training and development (T&D) programmes in varied organisational situations.
❖ To examine how performance expectation, effort expectancy, social influence, and enabling factors affect IT professionals' behavioural intention to use AI technology in T&D efforts.
❖ To provide meaningful suggestions based on AI integration and influencing factors for IT staff T&D AI adoption.

6. HYPOTHESIS OF PRESENT STUDY:
Hypothesis 1:
   Null Hypotheses (H0):
➢ There is no significant difference in the level of AI integration in IT employees' T&D programs across different organizational situations.
   Alternative Hypotheses (H1):
➢ There is a significant difference in the level of AI integration in IT employees' T&D programs across different organizational situations.

Hypothesis 2:
   Null Hypotheses (H0):
➢ The factors do not significantly influence IT professionals' behavioral intention to use AI technology in T&D efforts.
   Alternative Hypotheses (H1):
➢ The factors significantly influence IT professionals' behavioral intention to use AI technology in T&D efforts.

7. METHODOLOGY OF STUDY:

7.1 Research Design:
This mixed-methods study examines IT professionals' behavioural intention to use AI technology in T&D and assesses AI integration in IT employees' T&D programmes across organisational contexts. We'll send surveys to a diverse set of IT specialists from different firms to collect quantitative data. The poll will assess performance expectation, effort expectancy, social influence, enabling conditions, and AI technology use intention. AI integration in T&D projects will also be examined. Regression analysis and correlation tests will be used to evaluate variable connections and demonstrate statistical significance. Qualitative data will also be collected via interviews with key T&D decision-makers. These interviews aim to better understand IT professionals' intents to utilise AI technology and the organisational factors that affect AI integration in T&D. Interview transcripts will be thematically analysed to identify reoccurring themes. Combining quantitative and qualitative data may help IT experts understand where AI is in T&D, what's driving it, and how to improve it.

7.2 Sample Design:

This study's sample design will include 100 IT experts from various organisations to guarantee generalizability and validity. First, stratified sampling will classify organisations by industry, firm size, and location. It will represent diverse IT industries and account for organisational diversity in AI integration and T&D processes. Random sampling will pick IT professionals who are directly engaged in or impacted by T&D programmes in their organisations within each strata. IT trainers, T&D managers, and training participants are examples. To guarantee proper representation and statistical power for analysis, statistical power calculations will establish sample size. Purposive sampling will be used to acquire qualitative data via interviews to enrich insights. HR managers, T&D coordinators, and IT executives will be interviewed to give varied viewpoints on AI integration and factors impacting its acceptance in T&D activities. The sample design will prioritise variety, representativeness, and relevance to the study aims to explore AI integration in IT personnel' T&D programmes across organisational settings.

7.3 Data Collection:

To understand AI integration in IT employees' training and development (T&D) programmes and the factors influencing their behavioural intention to use AI technology, this study will use quantitative surveys and qualitative interviews. First, organised surveys of IT experts in various organisations will gather quantitative data. The survey will examine AI integration in T&D programmes, performance expectation, effort expectations, social influence, enabling variables, and behavioural desire to adopt AI technology. In-depth interviews with HR managers, T&D coordinators, and IT executives will provide qualitative data on T&D decision-making. These interviews will reveal organisational settings impacting AI integration in T&D and IT professionals' perspectives of AI technology's impact on their desire to employ it. Quantitative and qualitative data will be collected to triangulate findings and guarantee research reliability and validity.

8. LIMITATIONS OF STUDY:

This research intends to shed light on AI integration in IT workers' training and development (T&D) programmes and the elements that influence their behavioural intention to utilise AI technology, however it has some limitations. First, survey and interview self-report biases may affect the study's conclusions. Findings may also be limited by the sample's lack of diversity in IT organisational environments. Additionally, the cross-sectional research design may make causal linkages difficult to establish. Finally, participant data availability and quality, as well as resource and time restrictions during data collection and processing, may limit the research. The research seeks to illuminate the complicated dynamics of AI integration in IT T&D for IT professionals despite these constraints.

9. RESULTS AND DISCUSSION:

Multiple Regression and Correlation analysis has been carried between independent and dependent variables on SPSS to test the hypotheses.

Independent Variables:

FVL: Focusing on Virtual Learning
PLP: Personalizing the Learning Pathways
ITR: Integrating Training Requirements
RTD: Reinforcing Training and Development

Dependent Variables:

ELD: Effective Learning & Development

Table 1a: Data analysis using Regression model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin Watson
1	0.849	0.698	0.679	0.37289	4.122

a. Predictors: (Constant), FVL, PLP, ITR, RTD
b. Dependent Variable: ELD
The regression analysis shows that the model, which includes Focusing on Virtual Learning (FVL), Personalising the Learning Pathways (PLP), Integrating Training Requirements (ITR), and Reinforcing Training and Development (RTD) as predictors, has strong explanatory power for Effective Learning & Development (ELD). This means that independent factors explain 69.8% of ELD variation.
The adjusted R-squared value of 0.679 shows that the model fits well and explains 67.9% of ELD variation with the number of factors.
The standard error of the estimate (0.37289) shows the average distance observed data fall from the regression line, indicating model accuracy.
The residual autocorrelation is low (usually between 1 and 3), and the Durbin-Watson value of 4.122 shows that the data are independent.

These findings indicate that the model including FVL, PLP, ITR, and RTD may predict IT workers' Effective Learning & Development (ELD), with the predictors accounting for a considerable percentage of the variation in ELD.

Table 1b: Coefficient result values:

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig
	B	Std. Error	Beta		
Constant	43.117	0.331		130.316	0
PLP	-0.207	0.22	-0.02	-0.941	0.347
RTD	-0.104	0.184	-0.012	-0.566	0.571
ITR	-0.215	0.263	-0.017	-0.817	0.414
FVL	0.048	0.265	0.004	0.183	0.855

a. Dependent Variable: ELD

Interpreting the coefficient results:

In the absence of predictor factors (PLP, RTD, ITR, FVL), the constant term predicts the dependent variable (Effective Learning & Development, ELD). This constant is 43.117. This implies that ELD would be 43.117 without independent factors.

❖ PLP (Personalising the Learning Pathways): The coefficient for PLP is -0.207, suggesting that increasing PLP by one unit decreases ELD by 0.207 units, leaving all other factors fixed. PLP may not affect ELD since this coefficient is not statistically significant (p = 0.347).

❖ The coefficient for RTD is -0.104, meaning that for a one-unit rise in RTD, ELD decreases by 0.104 units, maintaining all other variables constant. Like PLP, this coefficient is not statistically significant (p = 0.571), demonstrating that RTD does not affect ELD.

❖ ITR (Integrating Training Requirements): The coefficient for ITR is -0.215, indicating that a one-unit increase in ITR decreases ELD by 0.215 units, leaving all other factors equal. This coefficient is not statistically significant (p = 0.414), demonstrating that ITR does not affect ELD.

❖ FVL (Focusing on Virtual Learning): The coefficient for FVL is 0.048, suggesting that a one-unit increase in FVL increases ELD by 0.048 units, leaving all other factors equal. This coefficient, like the other predictors, is not statistically significant (p = 0.855), demonstrating that FVL does not affect ELD.

The coefficients indicate that none of the independent factors (PLP, RTD, ITR, FVL) significantly affect IT personnel' Effective Learning & Development (ELD). Therefore, our research suggests that these characteristics do not substantially predict ELD.

Table 2: Correlations among respondents

Control Variables			FVL	PLP	ITR	RTD
ELD	FVL	Correlation	1.000	-.531	.664	.037
		Significance (1-tailed)	.	.000	.000	.400
		df	0	99	99	99
	PLP	Correlation	-.531	1.000	-.453	.157
		Significance (1-tailed)	.000	.	.001	.140
		df	99	0	99	99
	ITR	Correlation	.664	-.453	1.000	.043
		Significance (1-tailed)	.000	.001	.	.384
		df	99	99	0	99
	RTD	Correlation	.037	.157	.043	1.000
		Significance (1-tailed)	.400	.140	.384	.
		Df	99	99	99	0

Interpreting the correlation table:

❖ Focusing on Virtual Learning and Effective Learning & Development: FVL and ELD correlate -0.531. This negative correlation shows a moderate adverse link between FVL and ELD. As virtual learning becomes more popular, learning and development become less effective. Because this association is statistically significant (p = 0.000), it is unlikely to be random.

❖ PLP and ELD: PLP and ELD are -0.453 correlated. This negative correlation suggests a moderate unfavourable association between PLP and ELD. As learning routes get more personalised, learning and development become less effective. This association is substantial (p = 0.001), indicating that it is unlikely to be random.

❖ The correlation between ITR and ELD is 0.664. The positive correlation between ITR and ELD shows a moderate favourable association. Learning and development improve if training needs are integrated. Because this association is statistically significant (p = 0.000), it is unlikely to be random.

❖ RTD (Reinforcing Training and Development) and ELD: 0.037 association. A small positive correlation shows RTD and ELD have little in common. As training and development are reinforced, learning and

development may marginally improve, but the association is not significant (p = 0.400), suggesting it may have happened by coincidence.

Integrating Training Requirements (ITR) is favourably connected with Effective Learning & Development (ELD), whereas focusing on Virtual Learning (FVL) and Personalising the Learning Pathways (PLP) are adversely associated. Reinforcing Training and Development (RTD) may improve ELD, but not statistically.

10. Recommendations of the Study:

The report suggests various ways to improve IT personnel training and development (T&D) programmes:

❖ ITR has a strong positive link with Effective Learning & Development (ELD), thus organisations should integrate IT employee-specific training requirements. This may need detailed needs assessments and tailored T&D programmes to meet IT skill gaps and employment requirements.

❖ Focussed Virtual learning (FVL) negatively correlated with ELD, although organisations should use both virtual and conventional learning approaches. Virtual platforms provide flexibility and accessibility, but hands-on, experiential learning should not be disregarded.

❖ Despite the negative link between PLP and ELD, organisations should improve learning pathway personalisation to fulfil IT personnel' learning requirements and preferences. This might entail using technology to personalise learning, giving a choice of materials and modalities, and encouraging self-directed learning.

❖ Although the association between RTD and ELD was weak and non-significant, organisations should still prioritise training and development to retain and use new skills in the workplace. This might include frequent performance feedback, coaching and mentoring, and on-the-job skill practice and application.

❖ Organisations should continuously evaluate and enhance their T&D programmes, adjusting training methods depending on IT staff input. This might entail employee feedback, post-training assessments, and data analytics to monitor learning results and suggest areas for improvement.

These tips may improve IT employee T&D programmes, equipping them to meet industry needs and contribute to organisational success.

11. CONCLUSION:

In conclusion, this research shed light on IT staff training and development (T&D) programme efficacy. Integrating Training Requirements (ITR) is favourably correlated with Effective Learning & Development (ELD), whereas focusing on Virtual Learning (FVL) and Personalising the Learning Pathways (PLP) are negatively correlated. RTD had a modest positive connection with ELD, but it was not significant. These findings emphasise the need of adapting T&D activities to IT workers' requirements and preferences, balancing virtual and conventional learning techniques, and personalising learning paths. The results also emphasise the need of constant review and enhancement of T&D programmes to ensure they continue to educate IT workers with the skills and competences they need for success. These suggestions may help companies optimise their T&D efforts and create a trained, adaptive workforce that can thrive in the IT business. However, this study's self-reported data and unmeasured factors must be considered. Further studies should examine other variables affecting ELD among IT personnel and longitudinal impacts to better understand IT T&D dynamics.

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Artificial Intelligence On Human Resource Management- Innovation, Challenges And Path Forward

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ARTICLE INFO	ABSTRACT
	The introduction of the Artificial Intelligence (AI) technology has been a revolutionary innovation that has made several industries to sustain and grow in the current market. The implementation of AI in the Human Resource Management (HRM) has brought many positive changes to the system. Most of the studies demonstrated the benefits of implementing the AI based HRM process in the organization. Nonetheless, they failed to illustrate the prevailing HRM challenges which affects the organization and employees' performance. In this regard, this research is focused on conducting an empirical study on the impact of the AI in HRM system. The employees from different organizations and sectors of Hyderabad city in Andhra Pradesh were identified as the population for study and were presented with a survey questionnaire. The correlation test and one-way ANOVA tests were performed through the SPSS software package to validate the results. The outcome of the study identified that the possibility of errors and delay in attendance and salary management without AI assistance, replacement of manual work of HR management with AI-based applications has made the work simpler, and organizing activities for employees to maintain work-life balance through AI-based systems. Thus, the study concludes that the implementation of the AI-based tools for the HR management system is preferred and practiced by most organizations. The present study contributes in depicting the significance of AI driven HRM process in a non-IT organization. The AI-based HRM system effectively handles the salary and appraisal process of the employees which in turn simplify the recruitment and documentation process.

Keywords: Artificial Intelligence (AI), HRM, demographic, statistical analysis, correlation, ANOVA, SPSS. |

1. Introduction

The modern systems of the Human Resource Management (HRM) has gained more popularity in recent days, as the tedious and complex processes of various operations are digitalized [1]. The HRM has also found its way to gain attention in increasing the productivity, improving cost effectiveness and challenging market competitions through the implementation of electronic inventions of computer and internet [2]. The organizational, task-based and personnel data handled by the HR department are very large and thus caused the implementation of AI in strategic HR processes, thereby, improving the sustainability of the business models [3].

The major challenges faced by the HRM are related to working condition, strategies and practices. The managing the staffs, training and development, health management, performance management and employee relation are considered as the significance issues faced by the HRM. Nonetheless, these challenges can be overcome by the implementation of AI based HRM [4].

Many organizations have initiated the incorporation of the IT with their business through the implementation of advanced artificial intelligence, automation and machine learning technologies. The processing of complex and time-consuming tasks performed by the HRM functions have increased the influence of the AI-based solutions, in the perspective of HRM. The recent transformation of the HRM is significantly due to the innovations in the IT sector. The earlier technologies of the HR Information System (HRIS) and electronic-HR (e-HR) has helped the organizations to process digitally, store the processed data and then distribute it among the stakeholders of the organization. Nevertheless, the dependency on AI-based solutions, automation and interconnectivity in HR task processing, like the talent acquisition, has become popular and is developing swiftly [5].

The managerial HRIS highlights the significance of enhancing the motivation techniques towards employees to improve relationships at the workplace among the employees and organization [6]. The managerial HRIS elements corresponds to the technological advancements that improves the ability of the organization to develop and sustain with effective and professional intrapersonal and interpersonal relationship. In contradiction to the managerial HRIS, the practice of technical HRIS has a historic recognition reproducing the technical and data-controlled skills and capacities within the organization [7, 8]. The HRIS which is concerned of the managerial functions centralizes itself with the technologies of HR which enables to establish intrapersonal or interpersonal association in the organization. However, the HRIS which is concerned of the technical functions surrounds the information systems and technologies which establishes the technical understanding, analysis of data and effective flow of work [1].

The application of AI allows the organizations to develop innovative language translation and patterns of recognition through several algorithms to perform business in a global environment. Several research works have been carried out to understand the significance of AI in different business operations such as marketing, supply chain and operations management, and few research works included the functions of HRM [9]. The implementation of IT-oriented applications has enhanced the functioning of several business processes which includes the recruitment, marketing and finance [10]. The implementation of the AI-based technologies in the HR management system has also enhanced the effectiveness, precision and speed in various business processes. Therefore, the organizational transformation at a minimum investment can be achieved by integrating the machinery, manpower and methods through intelligent technologies [11].

The evolution of the Industry 4.0 (I4.0) has been a start for wide range of developments in the industrial era. The development of the artificial intelligence is also one among the revolutionary contribution of the I4.0 [12]. The implementation of the artificial intelligence technology in the HR management system for all the processes is still a challenge faced by many industries [13]. Despite the significance of implementing AI for the maximum of the functions of the HR management is recognized by the employees, these challenges still act as a barrier for the effective implementation and utilization. Hence, this concludes that the transformation of the AI-based HR management system is still in a developing stage and requires more focus and importance for a complete transformation [14].

The AI and AI-based technologies are incorporated in several organizations in the HRM department for people management. Over the past decade, the development in implementation of AI technologies in the HRM has increased, thereby initiating research in several relevant topics such as social impact of robotics and AI, impact of adoption of AI in the outcomes of business and individual levels, and assessing the AI-based HRM operations [15].

According to the IBM, 2020 [16], the AI is recognized as the most advanced improvement in the HRM system. These AI-based technologies facilitate the implementation of machine learning, deep learning and big data analytics in the HRM system, thereby increasing its efficiency [17]. It is well known from the earlier researches that the implementation of AI-based HRM tends to cause concerns with employees and adversely [18, 19] or positively impact employee and outcomes of business [20, 21].

Many researchers [22-24] investigated the benefits of AI oriented HRM system such as development, retention, talent acquisition and assessment in advanced technology multinational enterprises. Meanwhile, the current study investigated the variation between the HRM process before and after the implementation of AI. The issues without AI assistances are finance-oriented tasks, difficulty in planning activities for employees to maintain work-life balance, employee attendance and salary management. Nonetheless, these issues could rectified with AI-based HRM.

Most of the studies demonstrated the benefits of implementing the AI based HRM process in the organization. Nonetheless, they failed to illustrate the prevailing HRM challenges which affects the organization and employees' performance [25]. The previous research works have focused on several technologies that could be implemented for enhancing the HRM, but the feasibility of comprehensive transformation of the system has a very few research. Thus, the current study intend to fulfill the gaps in the prevailing research and depict the challenges of HRM process without AI.

Therefore, this research work is focused on different dimensions of the implementation of AI technologies in the HRM. An empirical study is conducted to evaluate the magnitude of impact on the different organizations through a survey conducted on sample population in a quantitative approach. The outcomes of this survey is inferred and the significance of the objectives and proposed hypotheses is statistically analyzed and validated. The following Section 2 discusses the previous research literatures on the AI-based HR management systems. The research design and proposed methodology is discussed in Section 3. The Section 4 provides the result

interpretation of the demographic and statistical analyses. The overall conclusion of the empirical study is concluded in the Section 5.

2. Literature review

The simulation of interactions among the humans which is made autonomous through technology-oriented communication systems was investigated by Pratt and his research team [26]. The model proposed in this research provided an insight regarding the employee performance and satisfaction with respect to motivational and cultural factors, communication methods and descriptions of work for the employees, individually. The model established the necessary factors that has to be considered for the AI-oriented tools for communication and their interaction between one another. The satisfaction of employees through motivation and direct influence is a bigger challenge for the AI-based communication tools since it is not equally effective as the Face-to-face methods. Therefore, the study revealed that the tactical methods of interacting with employees and creating a bond was challenging for the AI-based systems [1].

In another study, Garg and other researchers [25] established an understanding for the satisfaction of the employee within freight and logistics forwarding corporations through a novel approach developed to analyze satisfaction and feedback of the employee through the AI-based algorithms. These algorithms further allow the employees to undertake a climate-based survey relevant to their experience, thereby analyzing the input of the respondent and providing the organization stakeholders an insight to enhance the employee performance, commitment and retention. This analysis enables the researchers to establish an insight, both academic and professional, regarding the deep effect of AI utilization on the employees and their corresponding organizations. These AI-based technologies act as a benefit for the employees to voice their opinion and concerns to the organization directly [1].

As revealed by Malik and other researchers' [21] analysis, the AI-based algorithms enhances the cost-effectiveness of the HR and overall experience of the employee, thus, leading to an increase in satisfaction and commitment of employee in an organization. The differences in two generation employees, X and Y, and their adaptability towards the AI-driven social networking technologies is suggested by Kaminska and Borzillo [27]. The influence of the AI on the performance review of employee, relation of cognitive factors with quality of rating and differences of personality-oriented factors within HRM functions was systematically reviewed by Koch and other researchers [28].

The dissemination of IT in the theory of human resource management is investigated by Bilal H [5]. The study revealed that the leaders and executives of HR possess a positive attitude towards the implementation of AI to enhance the quality and efficiency of HRM. The positive attitude of the employees towards the implementation of the AI-based technologies for human resource management and their intention to involve themselves for the use of such technologies has supported the outcomes revealed by the study.

The technology of e-recruitment has gained more popularity recently and has been implemented by most of the organizations. This system enables the organizations to process the recruitment at a fast pace by reducing the expenses for the process and thus, attracts candidates with high potential globally. The corporate websites of the organizations provides the availability of various vacancies and opportunities in an organization to facilitate the recruitment process. Several websites, including careerbuild.com, mosnster.com, naukri.com etc. enables the recruiters to find the potential candidates for the appropriate position, and also enables the job seekers to find the links for various positions currently available in an organization [10]. The era of the internet facilities have made many contributions for several applications development, which enables various organizations to organize their business-oriented functions at a managerial level. This demands relevant competencies for decision-making processes to organize interactions with the stakeholders through Ai-oriented technologies, like the e-commerce [29]. The application of different technologies has substituted the human intervention as the advanced machines are programmed with AI-based algorithms that possess skills equal to humans [30].

S Kot with few other researchers [9] conducted an empirical study on the significance of AI-oriented recruitment process and the quality to identify the reputation of employer by adopting the technologies of artificial intelligence. The investigation of the effectiveness of AI adoption on AI-based recruitment was conducted in the Indonesian pharmaceutical industry. The study established the statistical significance of the AI quality and AI adoption relation with the reputation of the employer. The endogenous and exogenous structure of the effect of research revealed the effect of mediation due to AI adoption. In a brief, all the mediating and direct hypotheses relations were statistically observed to be significant, and it was recommended to the Indonesian pharmaceutical industries to implement the AI-based technologies for organizing effective business operations.

The socio-economic, political and, particularly, the technological transformations has brought a tactical popularity for the HRM in organizations [31]. However, few departments have not embraced these transformations, thereby, leading to slow and complex strategies [32]. In such circumstances, the implementation of advanced technologies, such as the AI, has to be considered [33]. The significance of implementing AI technologies is to enhance the effectiveness and performance efficiency of the HR-oriented operations to make different processes of management to be accurate and agile [34]. The control and understanding of data collection is performed through the AI technologies for the HRM processes, thereby,

including these processes in the tactics of economic and organizational efficiencies [35]. The HR managers and executives can provide more focus and contribution towards value-added tasks which seeks unique abilities and skills by making the time-consuming and repetitive tasks to be automated through the AI-based technologies [36]. The minimization and reduction of error through the machine learning enables to enhance decision-making through the provision of more information that are better-processed [33].

It is necessary for the HR departments to formulate a safe strategy to implement the AI in the organization by avoiding possible drawbacks, since the AI itself has its own weaknesses and strengths. The implementation of several disruptive and unsafe technologies will be essential to sustain the organization in the market [14].

In recent days, the investigation of AI and its effect on HRM operations has increased. For instance, according to several researchers, the developing AI-oriented HRM systems are useful in development, retention, talent acquisition and assessment in advanced technology multinational enterprises [22-24]. The AI technologies assists the HRM from the recruitment process till selection, evaluating and interviewing best candidates [37, 38], creating I4.0 advertisements regarding new profiles of jobs [39], and evaluate the effectiveness of employees' training [40]. Nevertheless, in spite of several options delivered through implement advanced technologies in the human resource management, the employees themselves are capable of performing many tasks which are not able to be performed by the machines [41, 42]. Hence, several researchers suggest that, the integration of AI with human support, instead of human being replaced completely, provides an optimum benefit to the organization [43].

Many recent research works also support the fact that the integration of human with AI-based technologies to perform HRM functions will improve the efficiency of the management in data collection, maintenance and validation [11]. The applications of the AI technologies enables the HRM to organize interviews in video mode through the internet facilities with the appropriate candidates, by evaluating the candidates' interaction, body language and attitude, and identify the potential candidate who would best fit the demand of organization [44]. These processes could be done completely without the intervention of humans.

3. Methodology

The current study embraced quantitative research method for evaluating accumulated data. The quantitative approach demonstrates the happenings through accumulating numerical unchangeable data that have been assessed with aid of mathematical techniques. This approach gives statistics allied to the interrogations of how, where, when, how much, what and how many. The quantitative approach includes objective, number stance and logic [45]. This research work employed an empirical study through a semi-structured questionnaire, and the data was collected from individuals of different age group and working domain. The questionnaire was categorized based on the study variables and the data are performed with the purposive sampling analysis. The hypothesis for the empirical study is defined based on the research objectives and interpreted through the quantitative assessment. A summary of the proposed research design is shown in Figure 1. The demography of the studied population was also observed and their corresponding responses were analyzed.
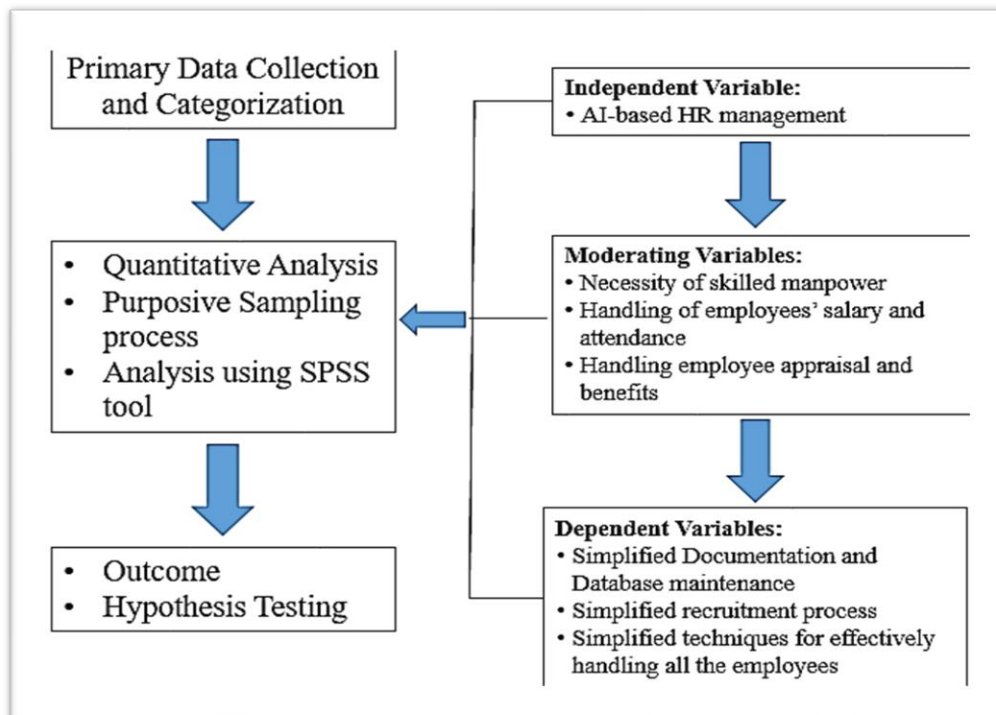

Figure 1. Research Design

The objectives of the present study are:
- To analyze the existing challenges in human resource management in an organization from different sectors.
- To study the impact of implementation of AI-based HR management in simplification of the various HR process.

Research questions are as follows:
- What are the challenges in existing HR management processes?
- How has the AI-based HR management implementation impacted in simplification and effective HR management?

The hypothesis of present study are:
H1: The implementation and functioning of AI-based HR management system has relationship with challenges in existing HR management processes.
- **H_1O:** The implementation and functioning of AI-based HR management system has significant relation with challenges in existing HR management processes.
- **H_11:** The implementation and functioning of AI-based HR management system has no significant relation with challenges in existing HR management processes.

H2: The simplified and effective HR management processes has relationship with the implementation of AI-based HR management system.
- **H_2O:** The simplified and effective HR management processes has significant relation with the implementation of AI-based HR management system.
- **H_21:** The simplified and effective HR management processes has no significant relation with the implementation of AI-based HR management system.

The study population is identified from various organizations of the Hyderabad district from the Andhra Pradesh state of India. The population are from different working sectors and domains. However, the perspectives and preferences of every individual on the implementation of the AI-based HR management system was understood through the study.

The study population was generalized, and hence, a total of 126 participants had registered their responses to the questionnaire. As mentioned, the respondents were from different organizations where the AI-based HR management system was implemented. However, all the individual respondents had the awareness about conventional HR management system and AI-based tools for executing HR-oriented activities. The identified participants were not restricted to HR management designation only, but employees working under different departments with different designations were also surveyed.

A sampling technique is significant to pile up the data from particular populace rather than focusing on entire populace [46]. Hence, it is significant for selecting relevant sample size to involve in the statistical study. Moreover, the sample size aids in making an implication based on the data gathered from sample populace [47]. Thus, the data were collected and the purposive sampling method was identified for conducting the statistical quantitative analysis. The participants of the survey were irrespective of their age, occupation, sector and designation. After the required data for the analysis was collected, the questionnaires were categorized based on the study variables.

Primary data is regarded as significant optimal data because the data are accumulated directly from the selected respondents. This data collection process incorporates structured questionnaire, survey and polls etc. [48]. The primary data required to perform the analysis of the study is collected through a semi-structured questionnaire. The general public are the participants for the survey, who work with different organizations in different positions. The researcher reviewed and verified the responses to each questionnaire for its completeness.

A standardized semi-structured questionnaire was adapted for the analysis of the primary data based on the five-point likert scale. The rating scale denoted 1 – Strongly Agree, 2 – Agree, 3 – Neither agree nor disagree, 4 – Disagree and 5 – Strongly Disagree. The responses of the questionnaire is converted to the likert scale and presented for analysis in the SPSS software.

The collected data is converted to a worksheet format for simplicity of analysis. The quantitative analysis of the collected data is performed based on the statistical approach. For this purpose, the Statistical Package for Social Sciences (SPSS) software package is used. The demography of the respondents is studied through the graphical analysis of the data presented in the worksheet. The survey questionnaire is encoded to corresponding factors and given as input to the SPSS software. The software performs the analysis based on the study variables and provides the outcome of the study. The input variables of the study are analyzed through three different approaches, namely one-way ANOVA and correlation.

4. Results

The data collected through the survey questionnaires are processed through the SPSS software and analyzed for its outcomes based on the study variables. The results satisfy the objectives of the study through the research design. Moreover, the detailed analysis of the responses based on the different demography is performed.

4.1. Demographic data and inferences

The Figure 2 represents the age group of the respondents to the questionnaire. It can be observed from the chart the only very few respondents are among the age group of above 55 years (13%). The impact of the implementation of the AI-based HR management system has made more influence towards the youngsters and middle-aged workers. About 28% of the respondents are below 35 years of age, another 28% of the respondents are aged between 36 year and 45 years and around 31% of the respondents are aged between 46 years and 55 years. The employees aged above 55 years have been practiced and used to the regular HR management processes and methods and thus feel it convenient that way than the AI-based HR management system.
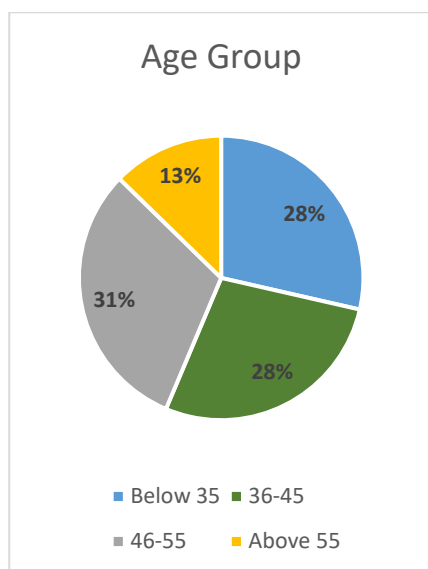

Figure 2. Age Group
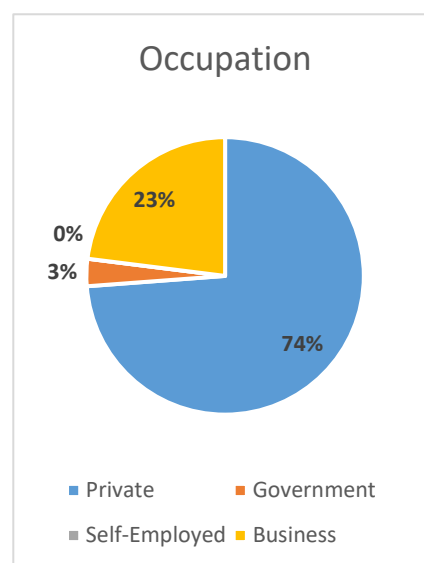
Figure 3. Occupation

The occupation of various respondents is plotted through a chart in the Figure 3. All the respondents are employed by some organization either way, and none of them are self-employed (0%). The majority of the respondents are employed with private organizations (74%), 23% of the respondents are handling their own businesses and only 3% of the respondents are government employees. The AI-based HR management system has been primarily implemented and most frequently used in many private organizations. This is because, the private organizations tend to continue functioning with minimum manpower and produce maximum output. Hence, the application of AI-based technologies enables such organizations to work in ease and with precision. The businesses handled by the young-aged and middle-aged respondents have also employed the AI-based HR management system. This makes to handle their business with more convenience and obtain more productivity. It is also observed from the chart that the government employees among the respondents are very few and they have very minimum exposure to the AI-based system for HR management. It is because most of the governmental departments and organizations are still functioning on the conventional methods and have not adapted for the advanced technologies. The government maintains enormous data which dates from the past 100 years. It is very difficult to convert those data to digital platforms and keep them under regular maintenance and update. However, few government departments have taken necessary procedures to digitalize few of their records and working functions, which is still far from digitalizing the HR management system.
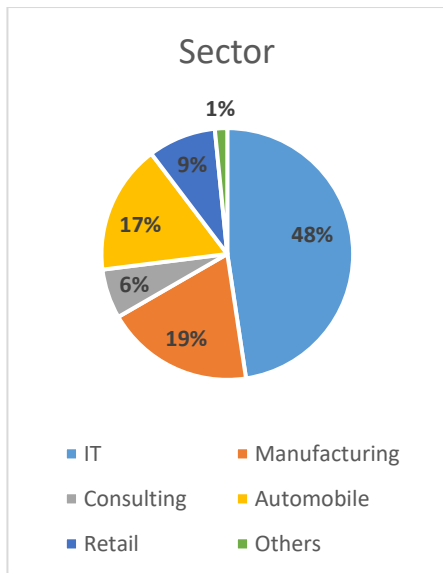
Figure 4. Sector
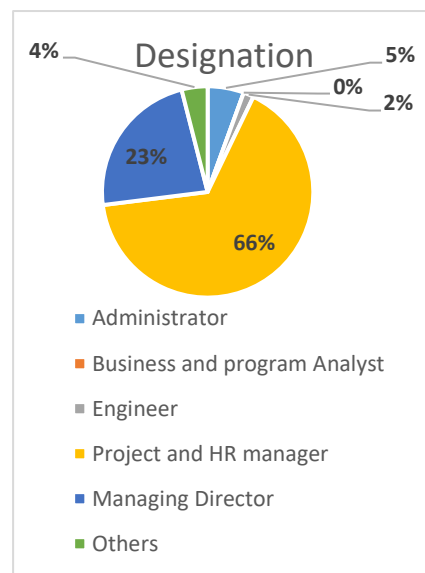

Figure 5. Designation

The respondents were identified from different industrial sectors (Figure 4). The purpose was to understand the awareness of AI-based HR management among different industries, and not only the IT industries. However, almost half of the respondents were from the IT sector (48%). 19% of the respondents were from the manufacturing sector, 6% of the respondents were from the consulting sector, 17% of the respondents were from the Automobile sector, 9% of the respondents were from the retail sector and only 1% of the respondents were from other domain of industry. Though the respondents from different sectors had sufficient awareness about the implementation of AI in HR management and its benefits, they still wanted to function on the conventional methods. This is because most of the manufacturing industries and automobile sectors had more number of employees, and managing of all employees through only AI system was not possible. Moreover, the nature of work for most of the employees is with machines and tools, but not computers or laptops. Whereas the IT industry employees are working with their computer and laptops only, hence, it is usually convenient for the HR department to handle their employees through the AI-based technologies.

The responses based on the designation of the participants is plotted in the chart shown in Figure 5. Although most of the organizations function with a separate HR management department, there are few organizations that controls the HR functions through other department executives and heads. Hence, this study has broadened its field of designation to other departments also. From the Figure 5, it can be observed that 5% of the respondents work as administrators, 2% of the respondents work as engineers, 66% of the respondents work as project manager and HR manager, 23% of the respondents work as managing directors and 4% of the respondents work in other designations. It is also noted that none of the respondents work as Business and program analyst. The task of HR management is tedious and hectic in large organizations. In such organizations, when any individual works with a different department, but holds the responsibility of the HR management, then the AI-based HR management system would be more convenient. Since the AI incorporates automated processes and involves less paperwork, it is simple and can be handled by an employee from different domains.
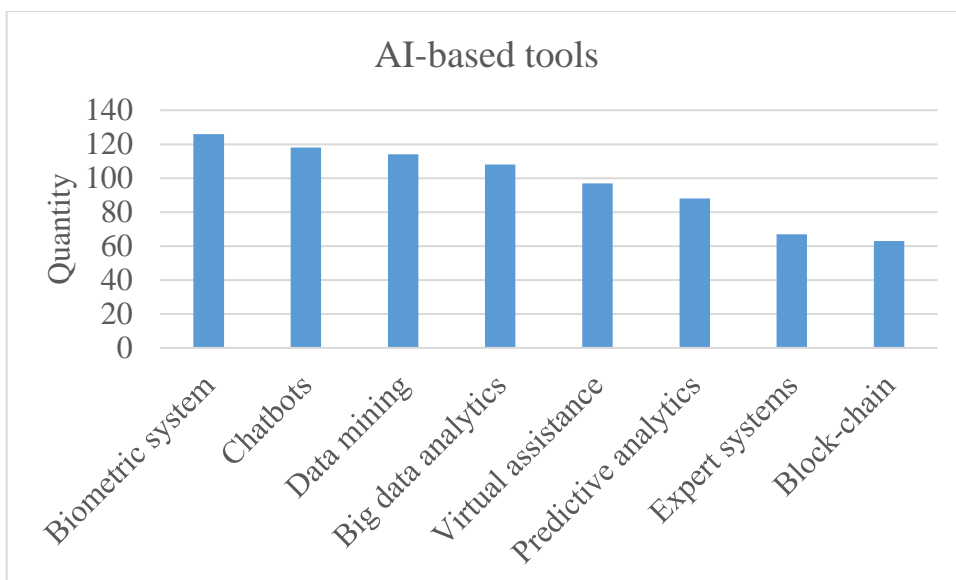
Figure 6. AI-based Tools

Each organization is transforming to AI-based technologies in many applications in order to simplify the working procedures and improve certain accuracy. Though the AI is capable of replacing most of the works done by humans, still it requires human assistance and monitoring for continuous progress and updates. Hence, most organizations have partially implemented AI-based applications in the HR management functions. The Figure 6 represents the different AI-based tools used in various organizations of the respondents. It can be observed that the face recognition and biometric system for registering the attendance of the employees has been implemented in all organizations of the respondents. The Chatbots are the user-friendly automated guide that pops-up when you open a webpage of an organization. The Chatbots enable the user to understand and know basic details of the organization and is capable of responding to primary enquiries of the user. The data mining and big data analytics are more useful and the mostly used tools of the AI. The virtual assistances are similar to the Chatbots and provide assistance to the user while opening the webpage of the organization. The blockchain technology, predictive analytics for the decision support and expert system are other tools of AI that are used in the HR management. Most organizations prefer the implementation of man-machine integrated systems for most of their operations to ease the work of manpower and also to improve the precision and time management of the task.
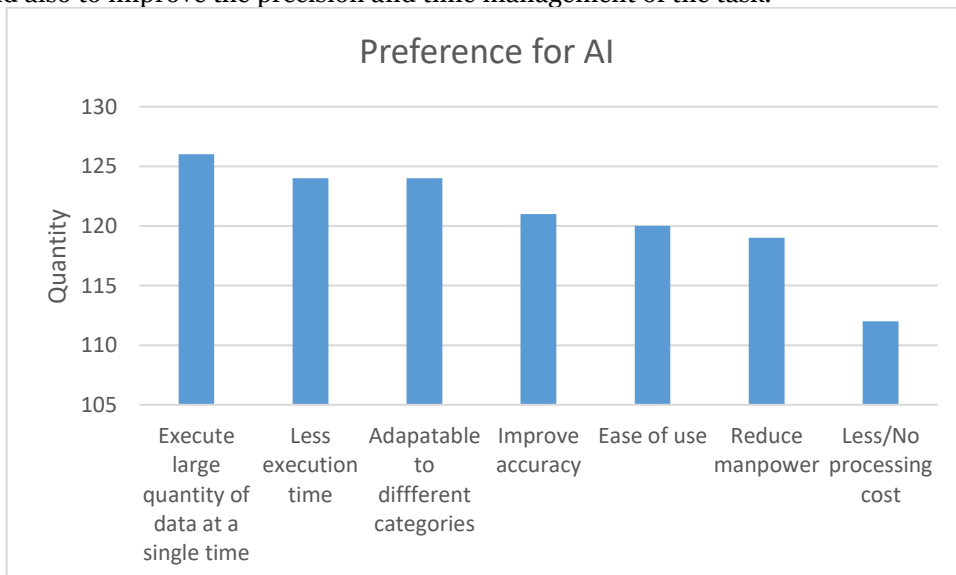
Figure 7. Preference for AI

The AI-based technologies are preferred for implementation in organizations due to various reasons. The AI provides many benefits and at the same time it is also considered a drawback in some cases. The various reasons for an individual to prefer the AI-based HR management system is depicted in the Figure 7. The different advantages considered for prioritizing AI are ease of use of tools, less time consumption for execution of given task, reduced manpower, improved precision, more data can be processed at a single time, the tool can be adapted based on the requirement, and the processing and maintenance cost is very lower. Although the AI tends to offer so many advantages, some category of people are still uncomfortable with the

use of AI-based tools. The study revealed that the individuals who were aged above 55 years and few individuals under the category of 46-55 years of age are used to the conventional HR management system which they had practiced throughout their tenure. These category of participants showed very less interest in the advancements of the AI-based technologies, finding it difficult for them to adapt and access.

4.2. Statistical analysis of the data

The data collected through the questionnaires were analyzed through the SPSS software package. The statistical analysis provides the relationship between the study variables and the objectives. This relationship enables us to understand the significance of objectives and validate the hypothesis. This study has performed two different statistical analysis procedures, the one-way ANOVA test and the Correlation test.

4.2.1. ANOVA test

The one-way ANOVA test is conducted to analyze the relation between the independent and dependent variables. The significance level of the test was obtained below 0.05, which is the nominal range to prove the hypothesis to have a significant relation to the objective. From the analysis summarized in Table 1, it can be inferred that the study variables of simplified finance-oriented tasks, difficulty in planning activities for employees to maintain work-life balance, employee attendance and salary management, and AI-based training and development programs possess a significant dependency on the independent variable of AI-based HR management at the significance level <0.05. Hence, the outcome of the one-way ANOVA test has proved that the study variables have significant relation to the objectives of the study, thereby validating the hypothesis of the research work.

Table 1. One-way ANOVA Test

		Sum of Squares	df	Mean Square	F	Sig.
Ease of finance-oriented tasks with more precision and less working time	Between Groups	51.819	4	12.955	24.992	.000
	Within Groups	62.721	121	.518		
	Total	114.540	125			
Planning of HR activities for employees to reduce work stress is difficult and time consuming	Between Groups	63.603	4	15.901	37.702	.000
	Within Groups	51.032	121	.422		
	Total	114.635	125			
Employee attendance and salary management is performed by AI with high accuracy without mistake	Between Groups	37.842	4	9.461	31.053	.000
	Within Groups	36.864	121	.305		
	Total	74.706	125			
The AI-based training and development programs are more effective than conventional methods	Between Groups	59.426	4	14.857	15.525	.000
	Within Groups	115.788	121	.957		
	Total	175.214	125			

4.2.2. Correlation test

The correlation test is performed to validate the relationship between the variables and also to estimate the magnitude of the relationship. The relationship between the dependent, independent and moderating variables is analyzed through this correlation test and summarized in Table 2. The significance of the hypotheses has been once again validated through this test. The significance was maintained below 0.05 throughout the analysis. The possibility of errors and delay in attendance and salary management without AI assistance, replacement of manual work of HR management with AI-based applications has made the work simpler, and organizing activities for employees to maintain work-life balance through AI-based systems are the variables that were tested for validating the significance of correlation. The significance correlation within the variables were all observed to be at the level of 0, thereby satisfying the 2-tailed significance condition of the bivariate correlation test. Hence, the correlation test also has proved that the independent, dependent and moderating variables possess significant correlation with one another.

Table 2. Correlation Test

		Errors and delay in attendance and salary management work is possible without AI assistance	AI has replaced manual work process of HR management and has made work simpler	AI-based system enables HR to organize online activities for employees to balance work stress
Errors and delay in attendance and salary management work is possible without AI assistance	Pearson Correlation	1	.348**	.443**
	Sig. (2-tailed)		.000	.000
	N	126	126	126
AI has replaced manual work process of HR management and has made work simpler	Pearson Correlation	.348**	1	.524**
	Sig. (2-tailed)	.000		.000
	N	126	126	126
AI-based system enables HR to organize online activities for employees to balance work stress	Pearson Correlation	.443**	.524**	1
	Sig. (2-tailed)	.000	.000	
	N	126	126	126
**. Correlation is significant at the 0.01 level (2-tailed).				

5. Discussion

The current study focused on the various dimensions of the implementation of AI in the HRM. It evaluated the impact of AI-based HRM on the HR process. Also, it demonstrated the challenges of HRM process. The effective HRM process after the implementation of AI has also been evaluated. The outcome of the study identified that the possibility of errors and delay in attendance and salary management without AI assistance, replacement of manual work of HR management with AI-based applications has made the work simpler, and organizing activities for employees to maintain work-life balance through AI-based systems. The study was focused on the impact of AI-based tools on the HR management system, and hence it was identified as the independent variable. The dependent variables were the tasks which were made simpler on implementing the AI-based tools. From the statistical analysis, the significance of the various dependent parameter with reference to the independent variable was established. The one-way ANOVA test revealed that the dependent variables and the moderating variables proved the hypotheses to be significant with the objectives and thus, validated the independent variable. The outcomes of the test established a dependency of the dependent and moderating variables on the independent variable. On the other hand, the correlation test was performed to establish the significance among the various study variables. The independent variable AI, has replaced manual work process of HR management and has made work simpler, moderating variable, Errors and delay in attendance and salary management work is possible without AI assistance, and the dependent variable were used for establishing the significance of correlation. The significance level among all the variables were observed to be well below the marginal level (P<0.05). Hence, the correlation test also validated the hypotheses.

The existing study [5] investigated dissemination of IT especially AI in the HRM. The study revealed that the leaders and executives of HR possess a positive attitude towards the implementation of AI to enhance the quality and efficiency of HRM. Meanwhile, the current study inferred that simplified finance-oriented tasks, difficulty in planning activities for employees to maintain work-life balance, employee attendance and salary management, and AI-based training and development programs are the prevailing challenges in HRM process. Nonetheless, these challenges can be rectified through the implementation of AI-based HRM system. The prevailing study [34] illustrated the significance of implementing AI technologies is to enhance the effectiveness and performance efficiency of the HR-oriented operations to make different processes of management to be accurate and agile. Similarly, the current study depicted the possibility of errors and delay in attendance and salary management without AI assistance, replacement of manual work of HR management with AI-based applications has made the work simpler, and organizing activities for employees to maintain work-life balance through AI-based systems.

Many researchers [22-24] investigated the benefits of AI oriented HRM system such as development, retention, talent acquisition and assessment in advanced technology multinational enterprises. Meanwhile, the current study investigated the variation between the HRM process before and after the implementation of AI. The issues without AI assistances are finance-oriented tasks, difficulty in planning activities for employees to maintain work-life balance, employee attendance and salary management. Nonetheless, these issues could rectified with AI-based HRM.

6. Conclusion and limitations

The human resource management plays a significant role in any organization, and thus needs continuous focus and improvement in its processes. The idea of implementing the AI-based technologies in the HR management system was revolutionary and has brought so many changes that has benefited the system. The present research work focused on the study of impact of implementing AI tools in the HR management system.

The major challenges faced by the HRM are related to working condition, strategies and practices. The managing the staffs, training and development, health management, performance management and employee relation are considered as the significance issues faced by the HRM. The salary management, errors and attendance management are also some of the significance issues faced by the HRM. In order to overcome those challenges, implementation of AI based HRM practices has been illustrated through the current study.

The participants aged above 55 years were dependent on the conventional HR management system and gave very less importance to the AI-based tools for HR management. Moreover, the participants from non-IT industries also preferred the conventional HR management system for most of the HR operations. This is because most non-IT industries function with large number of employees who do not have a direct access to computer or laptops or mobile phones to access the AI-based HR tools. Hence, these industries perform most of their HR task in the conventional methods only. However, some tasks such as attendance monitoring and salary calculation are done through AI-based tools only. The respondents were not only identified from the HR-oriented designations, but also were from other departments and designations. The AI-based tools made the tasks of the individuals who were from other designations than the HR-oriented. This platform gave them a simplicity to understand their work and also helped then to do it with very less or no errors or mistakes.

Thus, the study is concluded that the implementation of the AI-based tools for the HR management system is preferred and practiced by most organizations. This system has also eased the human efforts and increased the accuracy of various tasks that were performed. The present study contributes in depicting the significance of AI driven HRM process in a non-IT organization. The AI-based HRM system effectively handles the salary and appraisal process of the employees which in turn simplify the recruitment and documentation process. However, this study has also established certain limitations for the implementation of this system. The AI-based system, however, is automated and possess improved performance, it still requires human assistance and monitoring at certain stages. The present research has also been conducted for a specific population, and thus, the outcomes of the study are valid only for that populace. The upcoming study will keep this study as base to elaborately illustrate the technique of implementing the AI-based HRM system in the organization. Also, the future study will attempt to evaluate the benefits of AI-based HRM process in developed countries to make suggestion for effective implementation of AI in firms in the developing nation.

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