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Innovative Research Trends in Science and Technology Volume I

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Dr. Prasenjit Talukdar
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PREFACE

Science and technology have always been the cornerstones of human progress, driving innovation and transforming societies across generations. In today's fast-paced and interconnected world, research in these fields holds unparalleled significance as it shapes the trajectory of global development. With the constant evolution of knowledge, new trends in scientific exploration and technological advancement emerge, offering innovative solutions to the challenges of our times.

This book, Innovative Research Trends in Science and Technology, is a testament to the creative and relentless pursuit of excellence by researchers from diverse domains. It encapsulates cutting-edge studies and groundbreaking discoveries that highlight the dynamic interplay between science and technology. From fundamental scientific inquiries to practical applications, the chapters presented herein reflect the interdisciplinary approach that is increasingly defining modern research.

The contributors to this volume are experts and visionaries who delve into topics ranging from advanced materials, sustainable technologies, and computational sciences to life sciences, engineering innovations, and beyond. By bringing together these diverse perspectives, the book seeks to provide a comprehensive understanding of how novel ideas and research methodologies are shaping the future.

This compilation is not just a repository of knowledge but also a source of inspiration for scholars, professionals, and enthusiasts who wish to explore the frontiers of science and technology. It aims to spark curiosity, foster collaboration, and encourage further exploration in these vital fields.

We extend our heartfelt gratitude to the authors for their invaluable contributions and to all those who have supported the realization of this publication. May this book serve as a beacon for aspiring researchers and a platform for disseminating knowledge that propels humanity toward a brighter future.

- Editors

TABLE OF CONTENT

BOOSTING VEGETABLE GROWTH WITH SEED PRIMING TECHNIQUES

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Abstract:

Seed priming is a promising agricultural technique that enhances seed performance and resilience, particularly under adverse environmental conditions. By treating seeds with methods such as hydropriming, osmopriming, nutrient priming, and bio-priming, vegetable crops can exhibit improved germination rates, faster seedling establishment, and increased tolerance to abiotic stresses like drought, salinity, and temperature extremes. Additionally, priming can boost disease resistance and promote early growth, especially in nutrient-deficient soils. While the benefits of seed priming have been demonstrated across various regions of India, challenges such as the need for standardized protocols, the reduced shelf-life of primed seeds, and high costs of priming agents remain. These limitations call for continued research to refine techniques and make priming more accessible and effective for smallholder farmers, ultimately contributing to increased agricultural productivity and sustainability.

Seed priming is a pre-sowing technique that involves partially hydrating seeds to initiate early stages of germination without allowing radicle emergence. This method primes the seeds for faster and more uniform germination once sown in soil. Various seed priming techniques, such as hydropriming, osmopriming, and biopriming, have been utilized extensively in India to improve germination and crop establishment under diverse agricultural conditions (Kumar *et al.,* 2018).

Definition of Seed Priming

Seed priming refers to the controlled hydration of seeds to activate specific physiological processes, preparing them for rapid and synchronized germination upon planting. This treatment optimizes metabolic readiness, such as enzyme activation and nutrient mobilization within the seed. Seed priming methods like hydropriming, osmopriming (using salts), and biopriming (using beneficial microbes) are particularly advantageous for adapting seeds to variable environmental stressors. Studies by Sharma and Mehta (2019) have demonstrated the efficacy of osmopriming for enhancing germination rates in vegetable crops like tomato and capsicum in Indian regions with erratic rainfall.

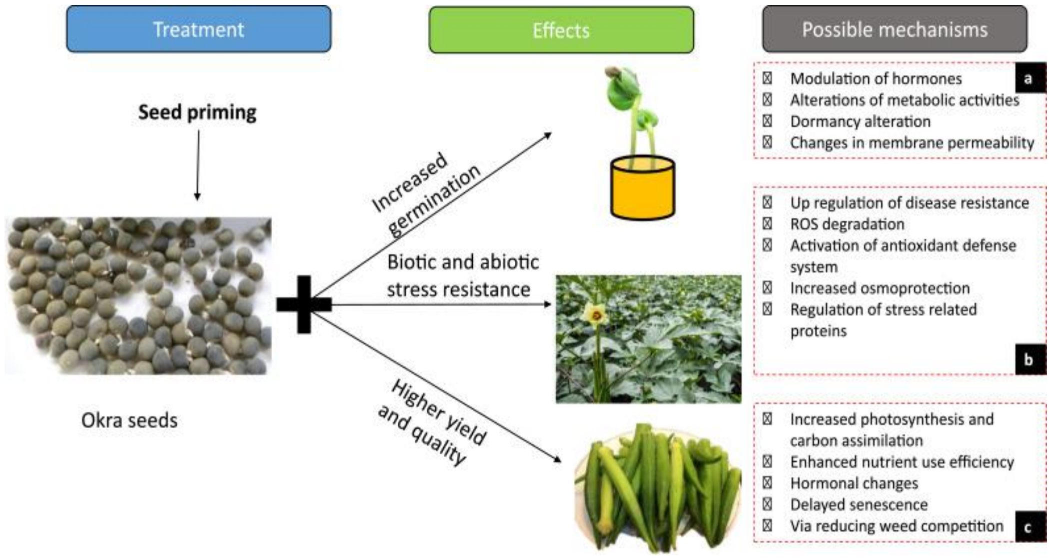
Importance of Seed Priming in Vegetable Crops

In India, vegetable crops are vital for both nutrition and economic value, making uniform seedling emergence and rapid crop establishment essential. Seed priming enhances these traits, ensuring better resilience under India's diverse environmental conditions. According to Rao and Prasad (2020), seed priming has increased crop establishment success rates, especially under suboptimal conditions such as temperature fluctuations and poor soil moisture, which are common in many Indian regions.

For instance, Patel *et al.* (2021) found that hydropriming in okra and bitter gourd led to a significant improvement in germination rates and uniformity, especially in arid zones of Rajasthan. Similarly, in West Bengal, priming techniques have been shown to enhance seedling vigor in leafy vegetables, leading to better crop quality and yield.

Overview of Benefits

- **Improved Germination**: Priming hastens germination and improves seedling uniformity, critical for early growth and yield. For example, studies in Maharashtra showed that primed seeds of spinach and radish achieved over 95% germination under field conditions compared to non-primed seeds, which had lower and inconsistent germination (Desai *et al.,* 2021).
- **Enhanced Resilience to Environmental Stresses**: Primed seeds display higher tolerance to stresses like drought, salinity, and temperature variations. This benefit is crucial for Indian agriculture, where climate extremes impact productivity. Research by Choudhary *et al.* (2019) in Gujarat demonstrated that osmoprimed cucumber seeds performed better in saline soils, common in coastal areas, compared to non-primed counterparts.
- **Higher Yields**: Enhanced germination and stress resilience support stronger plant growth, leading to higher yields. In trials conducted by Srinivas and Bhatia (2022), chili and brinjal primed seeds resulted in a 15–20% increase in yield. In regions like Andhra Pradesh, where vegetable crop productivity can be limited by water scarcity, seed priming has proven beneficial.



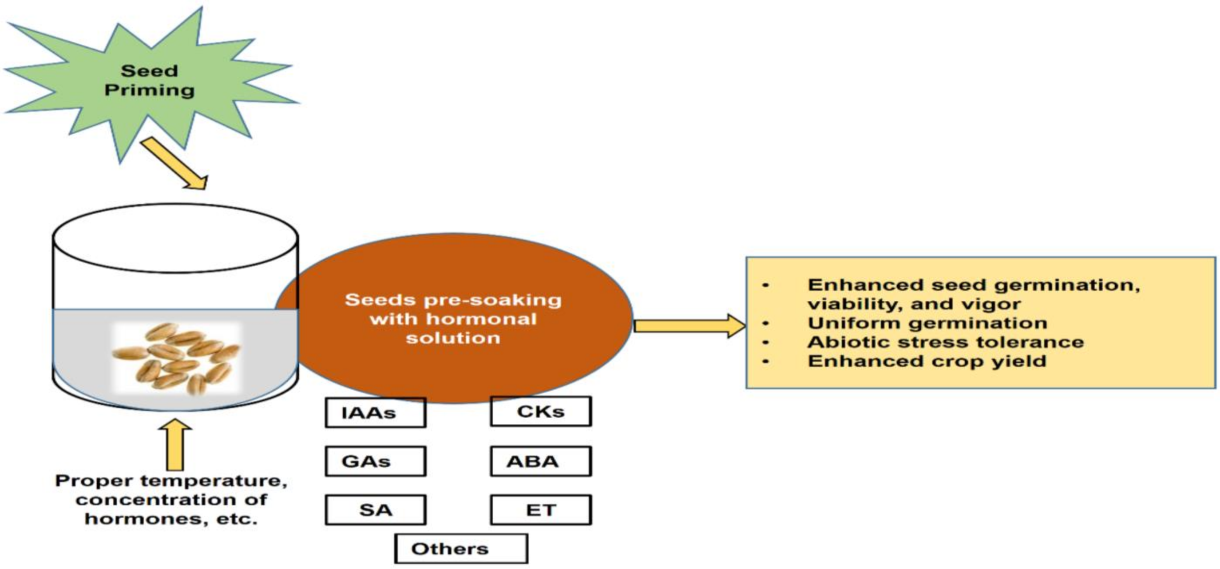
Effect of seed priming on Okra (Zulfiqar, 2021)

Types of Seed Priming Techniques for Vegetable Crops

Several seed priming methods are used to enhance vegetable crop performance, tailored to specific environmental conditions and crop needs. Each technique offers unique benefits, helping to improve germination, early seedling vigor, and stress tolerance.

1. **Hydropriming**: Seeds are soaked in water for a specified period, then removed and dried back to their original moisture content to prevent radicle emergence. The soaking duration varies by species; for example, cucumber seeds may be soaked for 4–8 hours, while larger seeds like pumpkins might require 12–24 hours. Hydropriming is simple, cost-effective, and helps to accelerate germination and improve seedling vigor. It allows seeds to better utilize soil moisture, supporting uniform crop establishment, especially in regions with erratic rainfall. Studies in arid regions of Rajasthan have shown that hydropriming enhances seedling emergence in cucumbers and melons, which are highly sensitive to soil moisture fluctuations (Sharma*et al.,* 2018).
2. **Osmopriming**: Seeds are soaked in a low-water potential solution, such as polyethylene glycol (PEG) or salts (e.g., KNO_3, NaCl), to limit water intake and control seed hydration. After soaking, seeds are rinsed and dried back to a suitable storage moisture level. Osmopriming enhances stress tolerance by initiating the activity of enzymes involved in stress response pathways, helping seeds survive challenging conditions such as drought and salinity.Research has shown that osmoprimed seeds of tomato and chili show enhanced tolerance to salinity, a common issue in coastal and semi-arid regions of India (Goswami*et al.,* 2019).

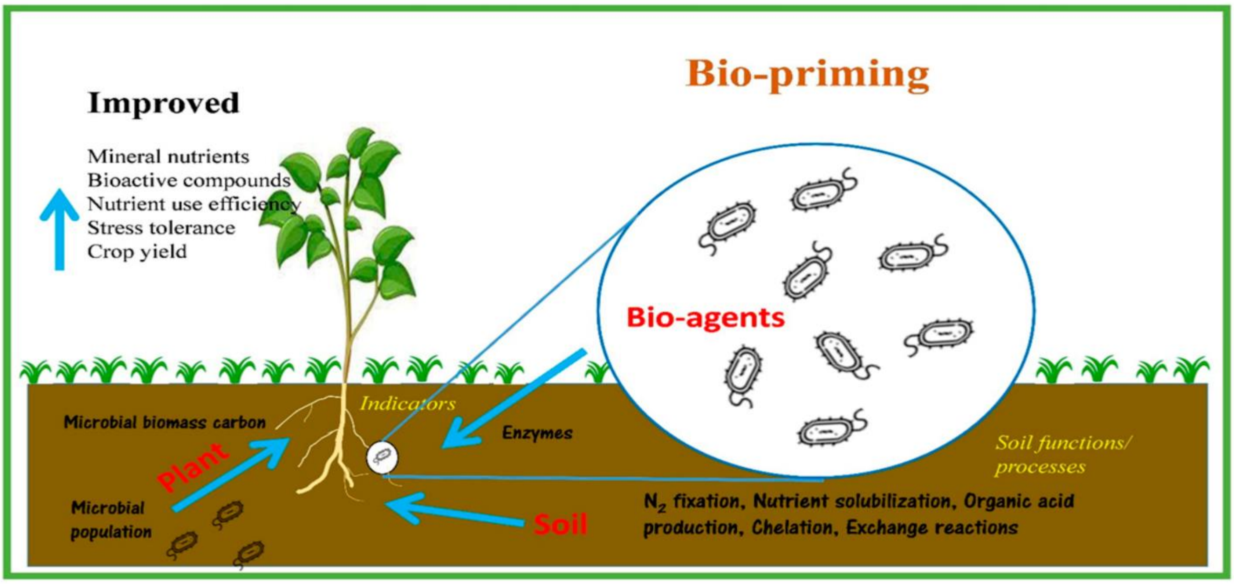
3. **Nutripriming**: Seeds are soaked in nutrient-enriched solutions, commonly containing phosphorus, zinc, or other micronutrients. The priming duration and nutrient concentration are carefully controlled based on the crop's requirements. Nutripriming provides seeds with essential nutrients that improve seedling growth and early root development, promoting a stronger start to the growing season. This technique is particularly beneficial for crops with high nutrient demands like tomatoes and peppers. Studies with nutriprimed tomato seeds in Karnataka showed increased seedling vigor, higher root biomass, and improved resilience to nutrient-deficient soils (Reddy *et al.,* 2020).
4. **Hormonal Priming**: Seeds are soaked in solutions containing plant growth regulators (PGRs), such as gibberellins, auxins, or cytokinins, which help stimulate cell division and elongation. The concentration of PGRs and soaking times are optimized to maximize efficacy without overstressing the seed. Hormonal priming can enhance seed germination rates, improve shoot and root growth, and increase tolerance to adverse conditions such as cold or heat. This technique is particularly valuable for crops with precise germination needs. Hormonal priming of lettuce and capsicum seeds with gibberellic acid in the Punjab region improved seedling growth and established uniform crop stands, crucial for commercial vegetable production (Singh & Kaur, 2019).



Schematic model showing possible effects of seed priming with phytohormones (Rhaman*et al.,* 2020)

5. **Biopriming**: In biopriming, seeds are treated with beneficial microbes, such as *Trichoderma*, *Pseudomonas*, or *Rhizobium* species, combined with a hydration step.

These microbes colonize the seed surface, aiding in disease suppression and growth enhancement. Biopriming protects seeds from soil-borne pathogens and boosts germination rates. The microbial coating enhances the plant's resistance to diseases, an essential aspect for high-value crops like cucumbers and tomatoes. Research in Maharashtra showed that biopriming with *Trichoderma harzianum* on cucumber seeds resulted in stronger seedlings and greater disease resistance in early growth stages (Patil *et al.,* 2021).

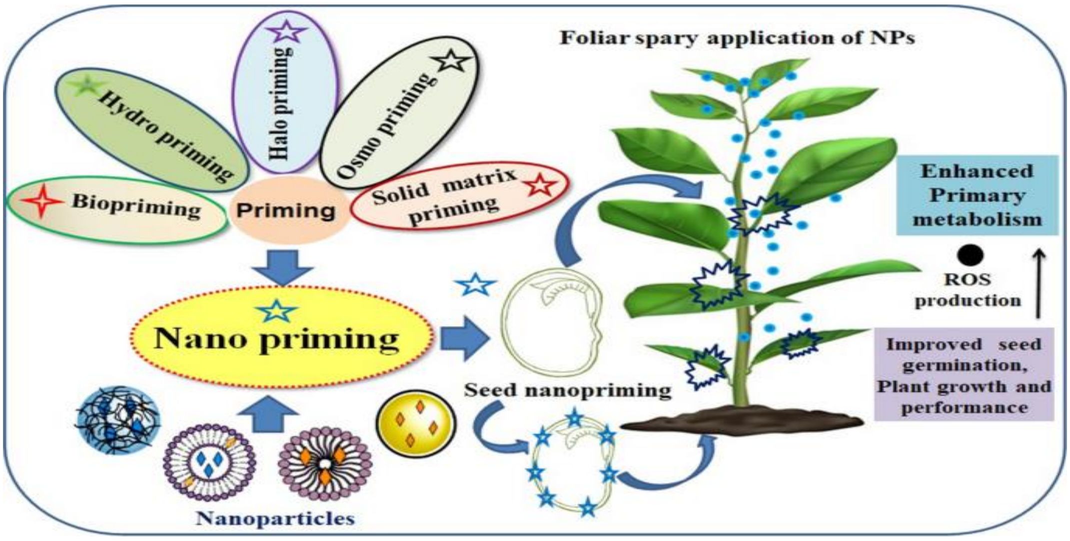


A conceptual model of bio-priming for soil health management (Sarkar ***et al.,*** **2021)**

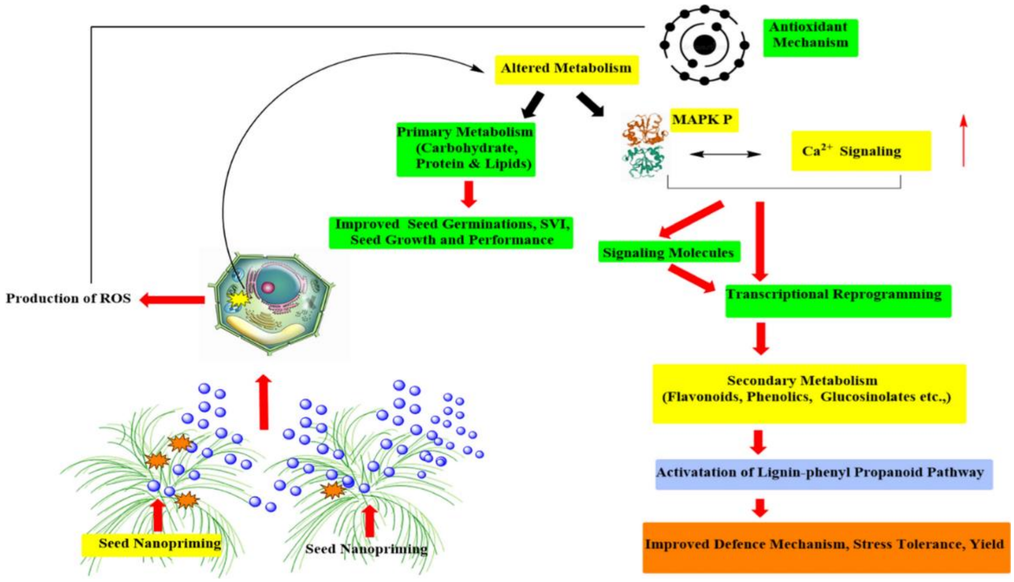
6. **Halopriming**: Seeds are soaked in solutions of salts (e.g., NaCl, KNO_3) to increase their salt tolerance. The salinity of the solution is controlled based on the crop's tolerance and regional conditions, and seeds are later dried back. Halopriming increases the salt tolerance of plants, which is beneficial in saline soils. It helps crops such as beans, carrots, and spinach germinate and grow better in coastal or salt-affected soils. In Gujarat, halopriming of spinach seeds with NaCl solutions improved germination rates and seedling health in salt-affected soils, showing promise for saline-prone agricultural regions (Joshi*et al.,* 2020).
7. **Solid Matrix Priming**: Seeds are mixed with a solid, water-absorbent material like vermiculite or diatomaceous earth, which provides a controlled hydration environment. The medium is moistened to initiate priming, and seeds are then dried back. Solid matrix priming provides a gradual water uptake, which reduces the risk of overhydration and stress. This technique is useful for large-seeded vegetables, ensuring uniform germination and root establishment. Studies with solid matrix primed beans and okra in central India have shown improved root length and

seedling vigor, making it suitable for mechanized planting and transplanting systems (Verma*et al.,* 2018).

8. **Nano Priming**: Nano priming involves treating seeds with nanoparticles of essential nutrients or growth-promoting compounds (e.g., ZnO, Ag, SiO_2 nanoparticles). The seeds are soaked in a nanoparticle solution that facilitates nutrient and water uptake. Nano priming has shown to improve germination and seedling vigor under stress conditions by enhancing nutrient availability and stress response at the cellular level. It is particularly promising in promoting resilience against abiotic stresses like drought and heat. Nano-priming of tomato seeds with zinc oxide nanoparticles has shown improved drought tolerance and increased antioxidant enzyme activity in trials conducted in Tamil Nadu (Kumar*et al.,* 2021).



Effect of nano-priming technology for sustainable agriculture (Nile *et al.,* 2022)



Influence of nano-priming on the primary and secondary metabolism in plants (Nile *et al.,* 2022)

Importance of Seed Priming for Vegetable Crops

Seed priming is a valuable pre-sowing treatment that can significantly improve seed performance, leading to better crop establishment and overall productivity. Here are some additional points emphasizing its importance, with relevant Indian references included:

1. **Accelerated Germination**: Seed priming helps in faster and more uniform germination, especially under suboptimal conditions. By partially activating the seeds before sowing, priming ensures that seeds germinate within a shorter time frame and at a consistent rate. Studies on tomato and cucumber in Rajasthan have shown that hydropriming and osmopriming techniques accelerate seed germination under varying moisture conditions, leading to quicker establishment of seedlings (Sharma*et al.,* 2018).
2. **Enhanced Stress Tolerance**: Seed priming enhances the ability of seeds to tolerate environmental stresses such as drought, salinity, and temperature extremes. By activating stress-response mechanisms within seeds, priming improves the resilience of seedlings. Research conducted in Gujarat showed that osmopriming and halopriming techniques effectively improved the salinity tolerance in crops like chili and cabbage, which are prone to soil salinity in coastal regions (Goswami*et al.,* 2019).
3. **Improved Nutrient Uptake**: Primed seeds are more efficient in absorbing nutrients during the early stages of germination. This allows seedlings to develop stronger root systems and better overall health, leading to more vigorous plant growth. Nutrient priming with phosphorus and zinc has been shown to enhance early root development in tomatoes and bell peppers in Karnataka, ensuring that plants receive critical nutrients for better growth and disease resistance (Reddy*et al.,* 2020).
4. **Higher Yields and Crop Quality**: Seed priming helps to achieve more uniform crop stands, leading to better plant growth, higher yield potential, and improved produce quality. Uniformity ensures that plants are more robust and productive. In Maharashtra, bio-priming with beneficial microorganisms on tomato seeds led to healthier seedlings, reduced plant disease incidence, and ultimately, higher-quality produce (Patil *et al.,* 2021).
5. **Potential for Early Harvest**: Priming allows for quicker seedling establishment, enabling earlier growth and development. This can result in an earlier harvest, especially beneficial for high-value crops that need to be harvested before the onset of adverse weather conditions. In Punjab, gibberellic acid hormonal priming in lettuce and capsicum crops accelerated germination, allowing for earlier transplanting and faster market-ready crops (Singh & Kaur, 2019).

6. **Improved Field Establishment**: Primed seeds tend to establish better in the field due to enhanced vigor. This leads to stronger, healthier plants that are more capable of overcoming challenges like pests, diseases, and soil compaction. In Haryana, solid matrix priming on okra and green beans resulted in better root anchorage and establishment in poor-quality soils, improving overall crop growth and establishment (Verma*et al.,* 2018).
7. **Reduced Seedling Mortality**: Priming helps in reducing seedling mortality rates by increasing seed vigor and enhancing resistance to biotic and abiotic stress factors that may otherwise cause seedling loss. Research on cucumber in Madhya Pradesh showed that biopriming with *Trichoderma* significantly reduced the mortality rate caused by soil-borne pathogens (Patil*et al.,* 2021).
8. **Optimized Water Use Efficiency**: Seed priming improves the ability of seedlings to use available water more efficiently, which is critical in regions facing water scarcity. It helps in better water absorption and retention, particularly in dry and drought-prone areas. In Rajasthan, osmoprimedcabbage and cauliflower seeds showed better water retention and reduced water stress during early growth stages, leading to improved yield under water-limited conditions (Sharma*et al.,* 2018).
9. **Enhanced Resistance to Pests and Diseases**: Some priming techniques, especially **biopriming**, can help seeds develop natural resistance to pests and diseases. The microbial treatments or nutrient enrichments can boost the plant's defense mechanisms, making them more resilient to biotic stress. Biopriming of tomato seeds with beneficial fungi and bacteria in Tamil Nadu resulted in enhanced disease resistance, reducing the need for chemical pesticides (Patil*et al.,* 2021).
10. **Improved Seed Quality**: Seed priming can help to improve seed quality by reducing seed coat impermeability and increasing the efficiency of germination. It can also help with the production of high-quality seeds that are more uniform in size, shape, and viability. Tomato and chili crops treated with nutrient priming in Karnataka resulted in superior seedling quality and vigor, making the seeds more viable for long-term storage (Reddy*et al.,* 2020).

Factors Influencing Seed Priming Success in Vegetable Crops

Seed priming is an effective technique to improve seed germination, stress tolerance, and overall crop performance. However, the success of seed priming is influenced by several factors, which determine how well the seeds respond to the treatment and how priming ultimately impacts crop performance. Below are the key factors that influence seed priming, with relevant Indian examples included:

1. **Type of Priming Technique**: The method of priming plays a crucial role in the effectiveness of the treatment. Different techniques such as hydropriming, osmopriming, halopriming, solid matrix priming, and nano-priming offer varying benefits depending on the crop type and environmental conditions. Osmopriming with salt solutions has been successfully used to improve salt tolerance in tomato and chili crops in Gujarat (Goswami *et al.,* 2019). Hydropriming and bio-priming have been shown to enhance germination and disease resistance in onion and cucumber in Maharashtra (Patil *et al.,* 2021).
2. **Seed Type and Quality**: Seed size, quality, and inherent vigor significantly affect the success of priming. Smaller seeds like lettuce and carrot may require less water and shorter priming times than larger seeds like beans or maize. High-quality seeds with fewer defects tend to show better responses to priming. Cauliflower seeds from Himachal Pradesh, which were primed under optimal conditions, showed better germination rates and seedling vigor compared to low-quality seeds (Reddy *et al.,* 2020).
3. **Moisture Content**: The moisture content absorbed by the seeds during priming needs to be carefully controlled. Too much moisture can result in premature germination, while insufficient moisture may fail to activate metabolic processes effectively. Research on green beans in Karnataka showed that maintaining an optimal moisture content during osmopriming enhanced seed vigor without inducing premature germination (Sharma *et al.,* 2018).
4. **Priming Duration (Soaking Time):** The duration of priming is critical. Short durations may not activate the seed's metabolic processes sufficiently, while prolonged soaking can lead to premature germination, which is undesirable. The optimal soaking time depends on the seed type and environmental conditions. Tomato seeds in Tamil Nadu benefited from a 12-hour soaking period during hydropriming, which resulted in faster and more uniform germination without compromising seed quality (Verma *et al.,* 2021).
5. **Temperature During Priming**: Temperature influences metabolic processes. Moderate temperatures accelerate these processes, while excessively high temperatures can damage seeds. Too low temperatures may require longer priming durations. Chili seeds in Rajasthan responded best to priming at 25°C, where the metabolic activation was optimal, leading to improved germination rates and uniform seedling growth (Goswami *et al.,* 2019).
6. **Priming Solution Composition**: The type and concentration of the priming solution are crucial for the desired physiological response. For example, osmopriming uses salt

solutions, nutrient-enriched solutions, and sometimes nano-particles to improve seedling vigor. In Madhya Pradesh, osmopriming with a potassium nitrate solution improved tomato seed germination under saline conditions, enhancing the crops' early growth and yield (Reddy *et al.,* 2020).

7. **Drying Conditions Post-Priming**: After priming, seeds need to be dried back to their original moisture content. Improper drying can lead to premature germination, loss of seed vigor, or mold growth. In Uttarakhand, okra seeds were dried at a controlled temperature of 30°C after priming to ensure proper moisture content and prevent spoilage (Verma *et al.,* 2018).
8. **Seed Storage Conditions After Priming**: Primed seeds are more sensitive to storage conditions. Exposure to high humidity, fluctuating temperatures, or prolonged storage can reduce their viability. Capsicum seeds primed in Maharashtra were stored in cool, dry conditions to prevent loss of seed vigor and ensure high germination rates when sown (Patil *et al.,* 2021).
9. **Environmental Conditions During Germination and Growth**: The environmental conditions at sowing time (e.g., soil temperature, moisture, and salinity) play a significant role in how well primed seeds perform. Seeds primed under certain conditions (e.g., saline priming) may perform better in similar soil environments. Cucumber seeds in West Bengal, primed with a saline solution, showed enhanced germination and growth when transplanted into saline soils, highlighting the importance of matching priming techniques with sowing conditions (Sharma *et al.,* 2018).
10. **Crop Type and Desired Outcomes**: Different crops have different responses to priming, and the desired outcomes (e.g., faster germination, enhanced stress tolerance, or early maturity) can determine the most suitable priming factors. Cabbage in Haryana benefitted from hydropriming for faster germination and early maturity, which helped in achieving an earlier harvest (Singh & Kaur, 2019).

Mechanisms Behind Seed Priming

Seed priming is an important pre-sowing treatment that enhances seed performance by activating various physiological, biochemical, and molecular processes. The mechanisms behind seed priming involve a complex series of changes that optimize the seed's potential for germination, growth, and tolerance to stress. Here's a detailed explanation of the mechanisms behind seed priming, with examples from Indian research.

1. Physiological Changes: Metabolic Pre-activation and Enzyme Activity Boost

Metabolic Pre-activation: Priming activates various metabolic pathways in the seed before germination, ensuring faster and more uniform sprouting once planted. By partially hydrating the seed, priming stimulates metabolic processes, including protein synthesis, enzyme activation, and cellular respiration. In tomato seeds from Gujarat, hydropriming resulted in faster germination rates due to the early activation of metabolic enzymes such as amylase and protease (Patel *et al.,* 2018). These enzymes are crucial for breaking down stored starches and proteins, providing the energy required for early seedling development.

Enzyme Activity Boost: Priming increases the activity of enzymes involved in seed metabolism, such as α-amylase, lipase, and invertase. This boost in enzyme activity aids in the breakdown of starch reserves, ensuring quicker access to energy during germination. Brassica species primed in Punjab showed significant increases in amylase and lipase activity after osmopriming with a potassium nitrate solution, which improved seedling vigor and germination speed (Singh & Bansal, 2020).

2. Biochemical Responses: Enhanced Antioxidant Levels and Hormonal Changes

Enhanced Antioxidant Levels: Seed priming often leads to an increase in antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), which protect the seed from oxidative stress. Primed seeds are better equipped to neutralize reactive oxygen species (ROS), which are typically generated during the germination process. In chili seeds from Maharashtra, priming with saline solutions increased the activity of SOD and CAT, reducing oxidative damage and promoting better germination under salt stress conditions (Patil *et al.,* 2019).

Hormonal Changes: Hormonal changes play a critical role in seed priming. Priming treatments often lead to an increase in the levels of gibberellic acid (GA), abscisic acid (ABA), and cytokinins, all of which regulate key processes in seed germination and early seedling growth. For instance, gibberellins stimulate the synthesis of hydrolytic enzymes, while ABA helps seeds cope with stress by regulating dormancy and delaying premature germination. Cabbage seeds primed in Haryana showed elevated levels of GA and cytokinins, which accelerated germination and improved seedling establishment (Singh & Kaur, 2020).

3. Genetic and Molecular Responses: Activation of Stress-Responsive Genes

Activation of Stress-Responsive Genes: Seed priming activates various genes associated with stress tolerance and germination. These include genes encoding for stress-responsive proteins such as heat shock proteins (HSPs), dehydrins, and enzymes involved in the synthesis of compatible solutes like proline and trehalose. In mustard crops in Rajasthan, hydropriming induced the expression of genes related to salt tolerance, such as NHX1 and SOS1, which enhanced seedling vigor and performance in saline soils (Joshi *et al.,* 2021). Similarly, genomic analysis of okra seeds treated with bio-priming in Maharashtra revealed the upregulation of genes involved in stress defense and cell wall strengthening, improving resistance to diseases (Deshmukh *et al.,* 2020).

Activation of Heat Shock Proteins and Stress Proteins: The priming process also activates the heat shock protein (HSP) family, which plays a key role in protecting cellular structures from heat stress. Dehydrins, proteins that help seeds manage water stress, are also activated during priming. Soybean seeds primed under osmotic stress in Madhya Pradesh showed enhanced expression of HSP70 and dehydrins, improving the seed's tolerance to heat and drought stress (Sharma *et al.,* 2019).

4. Epigenetic Modifications: While less studied, epigenetic changes (such as DNA methylation and histone modification) induced by priming could also contribute to the activation of beneficial genes. These modifications might influence the seed's long-term stress responses and overall growth patterns. In rice crops from West Bengal, seed priming with saline waterresulted in long-lasting epigenetic changes that enhanced the crop's ability to cope with saline conditions, suggesting the involvement of epigenetic regulation in priming (Banerjee *et al.,* 2020).

Practical Applications of Seed Priming in Vegetables

Seed priming is a valuable technique that can enhance vegetable crop performance in challenging environmental conditions. It is particularly effective in improving germination rates, stress tolerance, and early seedling vigor.

1. Priming for Drought Tolerance in Arid Areas: Drought-prone regions, such as Rajasthan, Gujarat, and parts of Tamil Nadu, frequently experience water scarcity, which affects seed germination and early growth. Priming can significantly enhance drought tolerance in vegetable crops by activating stress-responsive genes and promoting quicker establishment.

Priming Methods: Hydropriming (water priming), osmopriming (using osmotic agents like PEG or potassium nitrate), and nano-priming (using nano-particles or nano-encapsulated fertilizers). In tomato and chili crops from Rajasthan, osmopriming improved drought tolerance by upregulating dehydrins and proline synthesis, allowing seedlings to better manage water stress (Singh & Kumar, 2020). Similarly, okra seeds primed with PEG showed improved performance under water-limited conditions (Chandran & Awasthi, 2021).

2. Priming for Salinity Tolerance in Coastal Regions: Coastal regions of India, like West Bengal, Odisha, and parts of Andhra Pradesh, face issues with soil salinity, which hampers seed germination and crop establishment. Priming can help vegetable crops tolerate salt stress and improve seedling growth in saline conditions.

Priming Methods: Halopriming (using salt solutions such as NaCl or KCl) and osmopriming with saline solutions can improve seed vigor under saline conditions. Chili and brassica seeds from Kochi were primed with NaCl and showed better germination and growth in saline soil compared to untreated seeds (Nair *et al.,* 2019). Research conducted in Andhra Pradesh demonstrated that tomato seeds treated with osmotic priming in saline conditions had increased germination rates and seedling survival (Rajasekaran*et al.,* 2020).

3. Enhanced Germination in Cold and Heat-Sensitive Crops: Temperature extremes, especially cold and heat stress, can negatively affect seed germination and seedling growth. In areas like Himachal Pradesh and Uttarakhand, where cold temperatures delay germination, and in Punjab and Madhya Pradesh, where heat stress affects crop establishment, priming can enhance germination and growth under such stressful conditions.

Priming Methods: Hydropriming, hormonal priming (e.g., GA3), and nutrient priming (using solutions that contain micronutrients) are effective in overcoming temperature stress. In onion crops from Uttarakhand, cold priming (priming with water at low temperatures) significantly improved germination rates under cool soil conditions (Mehta & Singh, 2020). On the other hand, heat-primed capsicum seeds from Punjab showed enhanced germination and better seedling establishment when exposed to high temperatures (Gupta *et al.,* 2021).

4. Nutrient Priming for Nutrient-Deficient Soils: In many regions of India, such as Bihar and Madhya Pradesh, soils are deficient in essential nutrients like nitrogen, phosphorus, and potassium. Nutrient priming can significantly improve seedling vigor, growth, and productivity by ensuring that seeds have access to essential nutrients at the germination stage.

Priming Methods: Nutrient priming involves soaking seeds in solutions enriched with key nutrients like phosphorus, potassium, and micronutrients such as zinc and iron. Brassica seeds primed with phosphorus and potassium solutions in Madhya Pradesh showed improvedgerminationand early growth under nutrient-deficient soil conditions (Sharma *et al.,* 2019). Tomato and carrot seeds in Uttar Pradesh treated with micronutrient solutions like zinc sulfate showed improved seedling growth in soils with micronutrient deficiencies (Kumar *et al.,* 2021).

5. Priming for Disease Resistance in Vegetable Crops: Disease management is a significant concern in vegetable crops, especially in regions like Karnataka and Tamil Nadu, where soilborne pathogens and fungal diseases affect crop yield. Priming can improve the natural defense mechanisms of seeds against diseases. Priming Methods: Bio-priming (using beneficial microbes) and chemical priming can enhance seedling vigor and disease resistance. Chili seeds from Karnataka were primed with Trichoderma fungi and showed better resistance to soilborne diseases like Fusarium wilt and root rot (Reddy *et al.,* 2020). Similarly, tomato seeds primed with carbendazim in Madhya Pradesh exhibited enhanced resistance to fungal diseases, leading to higher germination rates and healthier seedlings (Sharma & Singh, 2021).

6. Priming for Improved Seedling Establishment and Early Growth: In regions with variable rainfall or erratic monsoon patterns like Maharashtra and Uttar Pradesh, priming ensures better seedling establishment and early growth, particularly for crops like cauliflower, spinach, and cabbage, which require stable growing conditions during early stages.

Priming Methods: Hydropriming, osmo-priming, and hormonal priming (e.g., with gibberellic acid or cytokinin) improve seedling emergence and early vigor. In cabbage cultivation in Maharashtra, osmopriming with KNO3 led to improved seedling establishment and faster growth, resulting in stronger plants with better resistance to early-season stresses (Gupta *et al.,* 2021).

Challenges and Limitations of Seed Priming in Vegetables

1. Variability in Response Across Different Crop Varieties

Different varieties of the same vegetable species can respond differently to seed priming treatments due to inherent genetic differences, environmental interactions, and the specific growing conditions required by each variety. In tomato and chili, priming treatments that enhance germination in one variety may not produce the same effects in another, which can complicate the application of seed priming on a commercial scale (Singh & Sharma, 2019). In India, where multiple varieties of brassicas and legumes are grown across diverse agro-climatic zones, the effectiveness of priming methods like osmopriming and bio-priming can vary significantly, limiting their widespread application.

2. Need for Standardized Protocols for Different Vegetable Species

There is no one-size-fits-all protocol for seed priming, and the lack of standardized procedures for different vegetable crops can hinder its adoption by farmers. A protocol effective for okra may not work well for carrot, as each crop has different moisture requirements, germination characteristics, and stress tolerance thresholds. In India, vegetable crops such as tomatoes, peppers, and onions are cultivated in various regions with distinct climatic conditions. The absence of universal guidelines for priming complicates the transfer of this technique to smallholder farmers across the country (Kumar *et al.,* 2021).

3. Limited Shelf-Life and Storage Challenges for Primed Seeds

Primed seeds tend to have a reduced shelf-life compared to untreated seeds, as they are metabolically active and more prone to premature germination or degradation if not stored under controlled conditions. After priming, cucumber seeds, if not dried and stored properly, can lose viability within a few weeks, affecting their ability to germinate when sown. In regions like Punjab and Uttarakhand, where weather conditions fluctuate greatly, the storage and shelf-life of primed seeds can become a critical issue, requiring sophisticated facilities for optimal seed storage (Sharma & Mehta, 2020).

4. Costs of Specialized Priming Agents and Equipment

The cost of priming agents (e.g., polyethylene glycol, salinity solutions, or nanoparticles) and specialized equipment (e.g., seed priming machines, controlled environments) can be prohibitive for small-scale and resource-poor farmers. In Maharashtra, where tomato and chili are widely grown, farmers may find it difficult to invest in high-quality osmotic agents or in systems required for uniform priming, such as hydropriming units. The high costs associated with some priming techniques may limit their adoption in economically disadvantaged regions, particularly in states like Bihar and Odisha, where farmers face economic constraints (Rao *et al.,* 2021).

Conclusion:

Seed priming is a highly effective technique that enhances vegetable crop performance by improving germination, seedling vigor, and stress tolerance under challenging environmental conditions such as drought, salinity, temperature extremes, and nutrient deficiencies. Methods like hydropriming, osmopriming, nutrient priming, and bio-priming have shown success in improving crop establishment and resistance to stresses, with applications across regions such as Rajasthan, Gujarat, and Tamil Nadu. However, challenges like variability in response across crop varieties, lack of standardized protocols, limited seed shelf-life, and the high costs of priming agents and equipment can hinder widespread adoption, especially among smallholder farmers. Overcoming these barriers through research and affordable, region-specific protocols will help maximize the benefits of seed priming for enhancing crop resilience and productivity.

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ADVANCEMENTS OF MATHEMATICS IN SCIENCE AND ENGINEERING

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Abstract:

The progress of mathematics is a critical development in science and engineering. The global community values the use of mathematics to enhance numerous disciplines of research and engineering. Mathematics is utilized as an operating tool to represent and solve a variety of real-world problems through the creation of mathematical models. The mathematical models are solved using a variety of methodologies and parameters in some novel approaches to represent diverse nonlinear complex systems in astrophysical contexts, as well as financial mathematics, economics, and chemical graph theories. The solution to diverse mathematical models examines the behavior of data connected with the complicated system.

Introduction:

A proper definition of Mathematics is usually difficult to achieve; yet, it is commonly considered that Mathematics is a branch of science that focuses on the quantitative and logical relationships between abstract and fundamental concepts. Mathematics development is motivated by both internal and external pressures, including the desire to cross boundaries and solve problems beyond the domain. In the sequel, we shall use the term “industrial mathematics” to refer to research focused on solving issues for industrial applications [1]. It is not a separate field from “pure mathematics” as it involves all fields of mathematics and poses new challenges to fundamental research on mathematical structure and methods. Vedic Hindus were particularly interested in two fields of mathematics: geometry and astronomy. Sacrifice was their primary religious pursuit. Each sacrifice had to be done on an altar of a specific size and shape. They were extremely particular about this, believing that even little variations in the shape and size of the altar would invalidate the entire ritual’s purpose and even have a negative impact. As a result, the sacrifice altar was meticulously designed and constructed to be the proper shape and size. As a result, geometry issues arose, as did the study of geometry. The study of astronomy began and grew primarily out of the need to determine the correct time for the sacrifice. This birth of the sciences as an assistance to religion is entirely natural, because it has been seen that a people's interest in a particular body of knowledge has been sparked and guided by specific motives throughout history [2]. The Vedic Hindu's specific reason was religious. However, throughout time, those sciences developed beyond their original goals and began to be studied for their own sake. The emergence of a specific level of mathematical knowledge driven by the practical requirements of a society is a widespread occurrence across all civilizations. What stands out is that Vedic Hindus exceeded these basic needs and cultivated a genuine passion for mathematics, aligning with their inclination toward abstract thought [3]. They tackled issues involving irrational numbers, elementary surds, indeterminate equations, and both arithmetic and geometric series while designing and constructing sacrificial altars. Although architectural challenges, the complexities of linguistic science such as meter and rhyme, and commercial bookkeeping contributed to the advancement of mathematics, its most significant motivation likely stemmed from the need to calculate time-based on the movements of celestial bodies [4].

The integration of computers and new technologies in schools is becoming increasingly prevalent and essential. It is crucial to discuss how and why these technologies are influencing education, particularly mathematics education. Technological innovations have historically directed human progress, sometimes causing revolutionary changes. The construction and use of complex artifacts are characteristic of human activities and contribute significantly at a cognitive level. The transition between practical application and intellectual understanding drives evolution and progress. Understanding the impact of technology on education requires identifying key discussion points around its use. New technologies are expected to be quickly and definitively incorporated into school practices. Human history is marked by technological advancements that have shaped its course. Norman's book provides illuminating examples of the interplay between practice and intellect in technological evolution [5]. The role of artifacts in human activities highlights their importance in cognitive development. In the modern days of science and technology, mathematics has grown very far from our imaginations. Various advancements in mathematics have been observed in the field of physical sciences i.e., of plasma physics in theoretical advancements in astrophysical environments [6-15]. In this paper, we will discuss the various fundamental concepts of mathematics that aid in the advancements of science and engineering in this modern-day world. We will also try to highlight some graphical representations of nonlinear systems that show the advanced application of mathematics in the higher level of problems in science and engineering.

Fundamental Concepts of Mathematics

There are various modern concepts of mathematics have been developed which are used in the advancement of science and engineering. However, there are some fundamental concepts based on which the advanced concepts of mathematics have evolved. Some of the fundamental concepts which have been discussed as follows:

- ***Decimal Place-value Numeration***: The advancement of arithmetic operations is widely observed during the expression of numbers. In the early ages of mathematics, Indian people conquered the advanced and excellent skills of mathematics such as Vedic mathematics, and their advantages in this branch of mathematics while discovering the concept of decimal place-value numeration. It implies that this system helps to express any number with the help of ten digits including zero. There are various studies have been found on this Indian decimal place value method of expressing any number, especially the placing of zero with decimal place-value notation. A lot of studies have also been performed on the transmission of this method to West Asia and South and Europe or Western countries leading to its international absorption.
- ***Algebra:*** It has been suggested that the many Sulvasutras of Apastamba, Baudhayana, Katyayana, Manava, and a few others are the origins of algebra, or more accurately, the geometrical techniques used to solve algebraic problems. The construction of various kinds of sacrifice altars and plans for laying bricks for them gave rise to these issues, which involved solving linear, simultaneous, and even indeterminate equations. After the techniques of indeterminate analysis (kuttaka) were developed, algebra began to be distinguished as a separate area of mathematics during the time of Brahmagupta. Brahmagupta denoted algebra using the terms kuttaka and kuttakaganita. Prthudakasvamin (A.D. 860) proposed the term "bijaganita," which means "the science of calculation with elements or unknown quantities."
- **Trigonometry:** Trigonometry was created as a crucial component of astronomy. Numerous astronomical computations would not have been feasible without its evolution. In ancient times, three functions were utilized and defined: utkramajya, jyat kojya (also known as kotijya), and jyat kojya. To enable quick calculations of astronomical elements, rather accurate sine tables were developed and included in the majority of astronomical texts. The data were often provided at 3°45' intervals, however other intervals were occasionally selected as well. Extrapolation was used to determine intermediate values. Brahmagupta, Bhaskara I, and others gave

formulas for the direct calculation of the sine of any angle without consulting any table. Thus, in trigonometry, there is evidence of an unbroken tradition of excellence and originality in India extending over several centuries.

- ***Calculus:*** Brahmagupta and Bhaskara II's writings contain rudimentary concepts of differentiation and integration. Bhaskara II, for instance, used a summation technique similar to integration to calculate the area and volume of a sphere. By drawing a series of parallel circles around any point on the surface, the first approach divides the surface into elementary annuli. According to Bhaskara II, there can be as many of these circles as one wants. The total of the annuli's areas yields the sphere's area. The sphere's volume is calculated by splitting it into several pyramids, each of whose bases and apices rest on the sphere's surface.

Governing Equations of some Nonlinear Phenomena

Many physical problems have various mathematical models. In this paper, we consider some nonlinear mathematical models which are based on advanced ordinary or partial differential equations. There are many mathematical models in the field of research work. But in this paper, we will highlight only the models based on plasma physics where the equation of continuity, equation of momentum, Poison's equation, Boltzmann distributed electrons and ions in the plasma.

In the case of inhomogeneous plasma, we consider a two-dimensional, unmagnetized, collisionless inhomogeneous plasma consisting of cold and hot isothermal electrons.

$$\left.\begin{aligned}
\frac{\partial n}{\partial t}+\frac{\partial (nu_x)}{\partial x}+\frac{\partial (nu_y)}{\partial y}=0\\
\frac{\partial u_x}{\partial t}+u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}+\frac{\partial \emptyset}{\partial x}=0\\
\frac{\partial u_y}{\partial t}+u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}+\frac{\partial \emptyset}{\partial y}=0\\
\frac{\partial^2 \emptyset}{\partial x^2}=n_e-n\\
n_e=\mathrm{e}^{\emptyset}
\end{aligned}\right\} \quad (1)$$

Where the terms used in the above equations have their usual meaning.

However, we can also consider some other mathematical model for inhomogeneous plasma is as follows:

$$\left.\begin{aligned} \frac{\partial n_d}{\partial t} + \vec{\nabla}.(n_d\vec{u}_d) = 0 \\ \frac{\partial \vec{u}_d}{\partial t} + (\vec{u}_d.\vec{\nabla})\vec{u}_d + \frac{5}{3}\sigma n_d^{-\frac{1}{3}}\vec{\nabla}\phi + \Omega(\vec{u}_d \times \hat{x}) + \Gamma\vec{u}_d = 0 \\ \vec{\nabla}^2\phi = n_d + \frac{(n_e - \delta n_i)}{(\delta - 1)} \\ n_i = n_{i0}(x)e^{-s\phi} \\ n_e = n_{e0}(x)[1 + (q-1)\phi]^{\frac{(q+1)}{2(q-1)}} \end{aligned}\right\} \quad (2)$$

where the terms used in the above equations have their usual meaning.

Various Applications of Mathematics in Science and Technology

From early history, mathematics has had a wide range of applications everywhere i.e., from counting numbers to the formation of humanoid robotics and from weighing some fundamental objects to calculating the distances from Earth to the astrophysical objects. The advancements in the study of mathematics have grown day by day in every sector of scientific and engineering domains. Many applications of mathematics in recent times have been observed in the field of science and engineering. Some of the recent and advanced applications of mathematics are listed as follows:

- **Mathematics in Academia:** From the ancient period to the modern education system, mathematics has been considered an integral part of the academic curriculum from the primary school level to college graduate level in every corner of the world. At the primary or high school level, students are taught a few subtopics of mathematics such as geometry, algebra, basics of financial mathematics, set theory, etc. to develop the reasoning and logical capacity of students at a young age. But at the higher level of school education, i.e., at the college level, in India, the choice is left to the student whether he or she will study or not mathematics as a subject in the future as a higher study. So, in college or university education, many things about mathematics have been taught by separating mathematics into two parts. One of them is pure mathematics and the other one is applied mathematics. In pure mathematics, mathematics is taught based on the theories and fundamental as well as extended concepts of mathematics such as real analysis, set theory, ring theory, number theory, linear algebra, group theory, etc. but in the case of applied mathematics, many things are taught based on the application of mathematics in various filed of science and engineering. Researchers have highlighted many applications of differential equations in finding the solution to various solutions and behaviors in nonlinear wave propagations. Some advanced differential calculus, integral calculus, and theories of complex analysis are also used to determine the dynamics and chaotic characteristics of various fluid models in fluid dynamics or fluid mechanics. Mathematics is also used as an interdisciplinary subject to study the behaviour of multi-players in *Game Theory* which is one of the recent and advanced fields of research area in both pure and applied mathematics. *Game Theory* is a combination of fundamental concepts of pure and applied mathematics and economics. Apart from these, a wide application of mathematics is seen in the field of physical sciences i.e., *Plasma Physics, Fluid Dynamics, Chaos, Cosmology, Astronomy, Dark Matters, Black Hole, etc.* and many more.

- **Mathematics in Industry and Engineering:** The essential program of the applied mathematician when collaborating with industry follows essentially the following paradigm: first, identify the problem of concern; then, build a quantitative mathematical model, analyze and solve it, apply the results, and potentially create appropriate mathematical software that can be commercialized. The emphasis is on pointing out which are the important and relevant variables controlling the problem, which are the constraints and what is the goal. This is done through the understanding of the underlying mechanisms involved in combination with the analysis of the respective observations and data. The next steps concern the analysis of the created mathematical model, its numerical simulation in different scenarios, and the validation of the model in comparison with experimental data. In addition, it is important to investigate the robustness and sensitivity of the model. Note that this is typically an iterative procedure since if the results do not explain or fit the observations, one has to modify and adapt the model, and repeat the cycle until the model describes – as accurately as needed – the situation to be studied or simulated. Typically, after the iteration of validating and adapting the model then, when the model is finally accepted, it would be used to improve, optimize, or control the process that it describes. Model-based control and optimization is a crucial element of automation in all areas of industry, often reducing the cost and time of product, process, and service innovation. In the modern age of science and engineering, many applications of mathematics and mathematical models have been observed in the field of science and engineering. Using mathematics and mathematical models' various problems of fluid dynamics, problems of mechanical engineering, bridge problems of civil engineering, problems of chemical graph networks, etc. are described and solved. After all, mathematics has an immense potential to develop the fundamental concepts in science and engineering.

- **Mathematics in Biological Sciences:** Many quantitative models are used in mathematical oncology to predict tumor growth and their measure of treatments. Based on the six following models, the theoretical concepts of mathematical oncology are developed. The six following models are as follows:
    a) the Exponential
    b) Logistic
    c) Classic Bertalanffy
    d) General Bertalanffy,
    e) Classic Gompertz and
    f) General Gompertz model.

Mathematical models are considered an important tool in cancer research which helps in describing and quantifying the physical and biological interactions between the tumours and immune system. These models also help the researchers to understand the dynamics of cancer growth and develop novel therapeutic approaches. There are various examples of mathematical models which are used in cancer research are as follows:

- **Tumor growth**: Usually, to describe tumor growth in cancer modeling, Deterministic Mathematical Models are used which help to replicate the behavior of various parameters obtained in the cancer study.
- **Breast cancer**: Mathematical models are also used to formulate and describe the dynamics of breast cancer and its dissemination and progression.
- **Breast and ovarian cancers**: One of the most common problems in the human race is breast and ovarian cancers. Here, the Mathematical models are also applied to discuss the role of BRCA1 mutations in hereditary and sporadic cancers.
- **Tumor immunology**: Cancer is a very dangerous and fatal disease that has been spreading rapidly around the globe. So, the mathematical models help to characterize the evolution of cancer within the patient and provide us with the information to implement the respective treatment.
- **Combination therapy**: In the case of cancer modeling, mathematical simulations can be performed to check the alternative protocols in the treatments of cancer therapy.
- **Chemotherapy**: Chemotherapy is considered one of the best and most available practices in cancer treatment. However, the differential equations are used to describe the impacts of chemotherapy on the treatment of cancer diseases.

So, we can say that, the mathematical models describe the dynamics of tumors and characteristics based on their mechanisms. However, similar to the mathematical models, the statistical models also provide various information depending on the correlated random variables.

Summary and Conclusion:

From the above discussions, it is obvious that mathematics has a wide range of applications in every discipline, especially in the fields of science and engineering. As, the whole of mathematics is divided into two special categories, i.e., one is pure and applied mathematics. In pure mathematics, most of the mathematical operations and derivations are found in the abstract form of theories. However, in the case of applied mathematics, the theories of various mathematical concepts are applied in the various disciplines of science and engineering. Especially, for example, differential and integral calculus are applied to detect the flow characteristics of fluid dynamics in different environments. Similarly, graph theories are applied to traffic signals, computer programming is applied to the functioning of ATMs, and game theories are applied to find the win-win situation or condition of any two or more players played in a real or abstract game. After all, we can conclude that mathematics is one of the most important subject disciplines which develops the ideas or concepts of any individual that he or she can create or generate some novel ideas and helps to get the best decision with very less time than the requirement.

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INNOVATIVE STEPS OF DEVELOPMENTS IN SCIENCE, TECHNOLOGY AND RESEARCH

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Abstract:

The present chapter describes various approaches to enhance innovations such as languages-security, entrepreneurship, artificial intelligence, nanoscience, and many more in the areas of scientific and technological research. It discusses breakthrough of technologies during the span of ongoing time with innovative scientific developments in the people's day to day lives and their work. This chapter also addressed the detail that achievement of intellectual economies by the innovative approaches of science and technology in the field of research and development is possible, but they must contribute the social as well as ecological aspects of people. In the outcoming section, it confers some specific policy-representations accepted by global communities of business and how far they are implementable and acceptable to the developing countries as their role-model. This chapter explores how technological innovation has operate histrionic changes in the field of information technology such as artificial-intelligence, natural languages processing, invention of various material-sciences and development of entrepreneurship etc.

Introduction:

The technological marvels do not come-out nowhere, whereas it involves decades of scientific research. The program which are structured and supplemented by certain skills or techniques definitely create the scientific, technological and research innovations. The provision of rich research contents under any learning process and the accessibility of user-friendly technological platforms surely are to be an incredible perspective for learners to acquire their next level [1-3]. The progressive innovations of any field are useful along with technological collisions of ideas, analysis, and then their verified outcomes will used for meaningful reproduction and improvement of context have considered. As a brilliant step to find innovation in the field of science and technology, the STARTALK (program funded by NASA, US) made a priority issue towards maintaining national security of various languages of the world like Greek, Arabic, Chines, Hindi *etc.* by producing videos and lesson-plans to spread languages globally, containing innovative-information [4]. A number of rich contents are available, full of innovations science and technology based in the ancient literature related to science, mathematics and medicine in Indian, chines, Greek, Arabic local languages, needs to be publish in global languages. For example – with no air-conditioning in the year of 1799, an Indian architectural design made, known as Hawa-Mahal (a palace of breezes) at Jaipur city of India having "Venturi-effect" in which air enters through narrow passages of building increasing the speed of flow of air and producing natural cooling in whole palace without using electricity. Such types of various other scientific innovations are available at various heritage sites across the world in their local languages, and can explored, taught and learned through videos, archaeological web-sites and various other electronic platforms under global prospects of research as innovative approaches.

Underpinning any success has been an exemplary record of innovation, but it is also worth noting that no scientist can solve alone the multidimensional problems as the process of solving any problem is mainly inter-disciplinary [5]. In fact, it is most important to understand that how the science has worked? The generation of brand-new concepts involves scientific innovation whereas technological innovations refer to the tools and systems used to implement these newly born scientific ideas. Experts believe that many innovative approaches related to science and technology research formulated in the past have not implemented due to lack of communication and mutual understanding between past and present economic-authorities; for example – a plan to improve any specific area/field in a country formulated, but during its implementation process another government was came into power due to various reasons, which may definitely interrupt the implementation of policy [7].

Exploring Areas: General and Specific

Some of the important kind of innovative approaches which have discussed and suggested here in this article, are necessarily and effectively adopt for the betterment of science and technology research nowadays. For example - we know that technology is changing abruptly at the global level presently, therefore, one country/organization should itself adopt these changes readily to their innovative policies with the pace of transition. Moreover, it is also necessary that the planned innovative approaches have continually been reviewing every year on regular basis. It is worth noting that the innovative policies made till now have not been able to adopt changes, if it will be reviewing after decades. In addition, to make innovative approaches more effective in science and technology research can be their inclusiveness [8]. If any adopted innovative policies are able to incorporate the suggestions which have given for a solution to the specific problem will surely strengthen the scientific and technological research in one way or the other. It is noteworthy that the innovative policies will integrate the lessons learned through challenging time as well as realize the demographic dividend opportunity in the field of research and development, design etc. through science, technology and innovation. In the formulating process of innovative policies, a setup of a forum of broad public and experts will be helpful as a dedicated platform to obtain inputs on thematic consultations for recommendation on science and technological research.

Innovation in any field do not develop on their own, its development depends on human consciousness, creativity and effort. Today, distance learning is not a new concept in the field of education, but a few years ago, it was a kind of innovation. Nowadays, with the help of many scientific and technological platforms and also with associating various research methodologies, the educational facilities in remote areas of the country rapidly increased through these innovative approaches [9].

Thus for, we have been discussing the innovative approaches in science and technology in general. Nowadays, artificial intelligence (AI) is another specific innovative approach which refers to generate new ideas and methods universally, it also addresses challenges or improve processes in the area of scientific and technological research. Artificial-intelligence (AI) is an innovative approach which gives computers the ability to analyze huge data multi-dimensionally, and come to educated conclusions which is frequently beyond the human capacity. AI has immense potential to transforms the area like healthcare, economic-growth, social and cultural aspects, cyber security, transportation etc. Recent years (2010-2024) have seen enormous achievements in the field of deep-learning, machine-learning and multiple-layer deep neural networks performed well in a range of applications such as vision-enhancing ability, natural language processing and many more [10]. But on the other hand, even though the potential benefits of any innovative approaches are tremendous, it is explicitly hard to express their moral consequences and potential dangers associated with its arrangement on the society at large, true for AI also.

Natural language processing (NLP) is another explicit innovative approach to increase the personalized assistance in the field of science and technology research [11]. The electronic platforms which allow these processing makes it easier for public to interlink and collaborate with the machines, by permitting them to execute the functions in the natural human language they use in their day-to-day life. By using NLP as innovative techniques, multiple aspects have been achieving to extract the information from unstructured contents. By these NLP innovative techniques, various useful tasks have achieved such as sentiment analysis, named entity recognition, word embeddings, text similarity and summarization *etc*.

Entrepreneurship also addressed as a virtuous innovative approach in terms of technological developments, because entrepreneurs identify opportunities where other see challenges. The joined creativity and strategic-action both together to produce a new technology or methodology by shifting paradigms. By this course of action, they will get the success to search new possibilities in the market [12]. For example – an entrepreneur who notices that small scale suppliers find difficult to access the market for their items, to supply. To bridge this gap, the entrepreneur comes with an innovative mobile app that connects suppliers and demanders directly by passing traditional costly distribution channels. This solution not only improves suppliers' execution by giving them better prices for their items but also provides quicker access to consumers.

As an overt way of innovation, the manipulating materials' structure and particle sizes during their synthesis methods at nano-scale developed enormous innovative solutions across scientific and technological research. Various nanomaterials have precisely developed by India such as nano-shells, nano-dots, nano-carbon-tubes *etc.* where manipulation of substance at dimension ranging from 1 to 100 nm has been achieving, which allow novel applications for them [13]. These materials are enabling processes more functional while nanoelectronics-power is faster, smaller or computing. Logic gates that developed using nano-scale components by IIT Bombay research team seems to pave the way for futuristic quantum computers. Nano-incubators are strengthening entrepreneurship by supplying funding which is useful to technology startup [14]. This is also a resourceful option for young researchers to create prototype system. India ranks third in 2023 in terms of demonstrating its ongoing commitment to expand its capacity in this evolving field of nanotechnology. Nanotechnology in India recognized in five-year plan by Indian government [15] which initiates various nano-science missions propelled in the growth of the Country.

Conclusion:

Scientific and technological research has revolutionized the way we work and live, and its innovative approaches transformed our world in many ways. It is important to hold the firm credence that what-ever the research and development in science and technology achieved in this twenty-first century, must be faithfully passed-on to future generations as an irreplaceable asset. In conclusion, the comprehensive relationship between innovative approaches in scientific and technological research is dynamic and symbiotic as science provides the fundamental knowledge and understanding on an issue, which can lead to technological development on that particular subject. Further, these technologies, in turn, often ignite the innovation as they have applied in creative ways to solve problems, search new markets and improve the quality of life in the society. The synergy between science, technology and innovation is a corner-stone for the betterment of people's life in the modern society. While these approaches brought many benefits, it has also had some negative consequences. Therefore, we continue to develop new research and technologies, we must remain mindful of their impact on our environment, society and culture.

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DEPOSITION OF THIN FILMS BY ELECTRODEPOSITION METHOD

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Abstract:

Electrodeposition is a well-established technique for producing high-quality thin films with precise control over thickness and composition. This electrochemical process involves the reduction of metal ions from a solution onto a conductive substrate, enabling the growth of films with diverse properties and applications. Key advantages of electrodeposition include its simplicity, cost-effectiveness, and scalability. It allows for the deposition of a wide range of metals, alloys, and even composite materials. Moreover, precise control over deposition parameters such as current density, electrolyte composition, and temperature enables the tailoring of film microstructure and properties, including crystal orientation, stress levels, and even the incorporation of nanostructures.

Electrodeposited thin films find widespread applications in various fields, such as electronics, coatings and energy storage. This book chapter provides a concise overview of electrodeposition, highlighting its key features, advantages, and applications. This book chapter deals with basics of electrodeposition, advantages and brief discussion about the different types of electrodepostion deposition methods.

Introduction:

Electrodeposition (ED) is one of the most popular chemical methods today for preparing conducting and semiconducting thin films. This technique is extensively used across various industries, including automobile, aerospace, marine, machinery, electronics, jewelry, defense, and toy manufacturing [1-5]. At the core of the electrodeposition process lies the electrolytic cell. This cell consists of an anode, a cathode, and an electrolyte bath, through which an electric current is passed to facilitate material deposition.

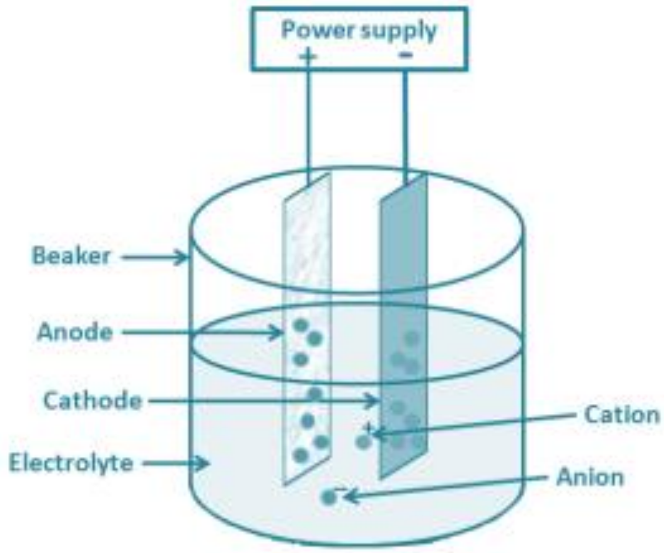
In recent years, electrodeposition has been widely employed to fabricate thin films of semiconductor materials, conducting polymers, and composites of conducting polymers with semiconductors. Furthermore, this method enables the deposition of micro- or nano-layers of semiconductor materials or conducting polymers onto pre-existing materials on a conducting substrate, expanding its versatility and applications in advanced material science.

Advantages of Electrodeposition:

1. Cost-Effectiveness: Electrodeposition is a low-cost method for producing thin films, as it uses relatively inexpensive equipment and materials. It also eliminates the need for vacuum systems, making it an attractive choice for large-scale industrial applications.
2. Control Over Film Thickness: The process allows for precise control over the thickness of the deposited layers, which can range from nanometers to micrometers. This is particularly useful for applications in electronics and coatings.
3. Versatility in Materials: Electrodeposition can be used to deposit a wide range of materials, including metals, semiconductors, conducting polymers, and composite materials. This flexibility supports diverse applications in fields such as energy storage, sensors, and microelectronics.
4. Uniform and High-Quality Coatings: Electrodeposited films exhibit uniform thickness and excellent surface morphology, making them ideal for high-performance applications, such as semiconductors and coatings for aerospace and defense industries.
5. Scalability: The method can be scaled up easily for industrial production, with the ability to deposit large-area thin films, making it suitable for mass manufacturing in industries like automotive and electronics.
6. Environmental Benefits: Electrodeposition is a relatively green method compared to other deposition techniques like sputtering or CVD (chemical vapor deposition). It generates fewer emissions and uses less energy, making it more environmentally friendly.
7. Ability to Deposit on Complex Geometries: Electrodeposition can be performed on various substrates, including those with complex shapes, offering an advantage for coating parts with intricate geometries in industries such as aerospace and machinery.
8. Improved Adhesion and Bonding: The electrochemical nature of the process results in strong adhesion between the thin film and the substrate, providing enhanced durability and longevity of the coatings.

Basic mechanism of Electrodeposition

The schematic of an electrodeposition setup with two electrodes. The cathode, anode, and electrolyte make up an electrolytic cell. An electrolyte is an electrical conductor where ions, as opposed to free electrons, carry current (as in a metal). An electric circuit between two electrodes is completed by electrolyte. Electrolysis is the term for the chemical processes that occur at the contacts between the circuit and the solution when a direct electric current flows through an electrolyte. When an electric current is applied, the electrolyte's positively charged ions will flow toward the cathode and its negatively charged ions toward the anode. A cathode that is connected to the external electric supply's negative terminal and provides electrons to the electrolyte is depicted in Fig. An anode, on the other hand, takes in electrons from the electrolyte since it is attached to the positive terminal of the external power source. During electrolysis, a variety of reactions occur at the electrodes. Generally speaking, oxidation occurs at the anode while reduction occurs at the cathode.



Schematic of Electrodeposition

Modes of Electrodeposition

1. Potentiostatic

Potentiostatic mode, a widely utilized electrochemical technique, involves maintaining a constant potential across electrodes to achieve controlled deposition of thin films. This method is particularly effective for synthesizing materials like metal chalcogenides, metal oxides, and compound semiconductors. Under constant potential, ions migrate toward their respective electrodes and undergo adsorption, enabling precise film formation. The working electrode potential is carefully controlled relative to a reference electrode, ensuring consistent quality and repeatability in the deposition process.

This technique has found applications in diverse fields, with numerous studies reporting successful thin film deposition. Wilman *et al.* [6] synthesized cuprous oxide thin films optimized for photovoltaic applications, while recent advancements have demonstrated its utility in fabricating high-performance electrode materials for energy storage systems (Li *et al.,* [7]). Additionally, research by Zhang *et al.* [8] highlighted its role in producing thin films for water-splitting devices. The output of potentiostatic processes, typically represented as a current-time plot, offers insights into deposition kinetics and film characteristics.

By leveraging the precise control of the potentiostatic mode, researchers continue to innovate in thin-film technology for applications spanning energy, electronics, and environmental science.

2. Galvanostatic

In galvanostatic mode, thin films of materials such as metal chalcogenides, metal oxides, or compound semiconductors are synthesized by maintaining a constant current between the working and counter electrodes during the deposition process. The amount of material deposited on the substrate is directly proportional to the total charge passed through the electrolyte, following Faraday's laws of electrolysis. Achieving uniform deposition requires maintaining a consistent current density across the electrode surface throughout the process. The output of a galvanostatic deposition is typically a potential-time plot, which provides insights into the process dynamics and film quality.

Recent research has highlighted the efficacy of this method in various applications. For instance, Liu *et al.* [9] demonstrated the galvanostatic deposition of cobalt oxide thin films for supercapacitor electrodes with excellent electrochemical performance. Similarly, Das *et al.* [10] reported the synthesis of cadmium selenide thin films for optoelectronic applications using this technique. Moreover, Patel and Sharma [11] utilized galvanostatic methods to fabricate zinc oxide films for photocatalytic water purification.

3. Potentiodynamic (Cyclic voltammetry)

Potentiodynamic methods, such as cyclic voltammetry (CV), involve measuring electrolysis currents as a function of an applied potential. This technique is instrumental in studying electrochemical processes like charge transfer and electrode kinetics, providing insights into reaction mechanisms. Recently, CV has gained prominence as a deposition method, especially for synthesizing conducting polymers like polyaniline and polypyrrole. During a triangular potential sweep, anodic and cathodic responses are observed as forward and reverse peaks in the current, offering valuable information about the electroactivity of the electrode or electrolyte solution.

Electrodeposition, including CV-based approaches, is a cost-effective and versatile technique for preparing nanocrystalline metallic materials and conducting polymers as coatings or thin films. The low processing temperature minimizes interdiffusion and unwanted chemical reactions, ensuring the integrity of the films. Moreover, the film thickness can be precisely controlled by optimizing deposition parameters. Electrochemical techniques like CV and chronoamperometry (CA) play dual roles: they act as deposition methods and are critical for analyzing reaction mechanisms.

Recent studies emphasize the efficacy of CV in deposition processes. For instance, Wang *et al.* [12] reported the use of CV to deposit polyaniline films for biosensor applications, while Patel *et al.* [13] highlighted the role of CA in controlling the growth of nickel oxide thin films for energy storage devices.

Conclusion:

Thus, Electrodeposition is a versatile and cost-effective method for synthesizing thin films of metallic materials, metal oxides, and conducting polymers. Its three modes—potentiostatic, galvanostatic, and potentiodynamic—offer precise control over film thickness, morphology, and composition. This technique is widely used in applications such as energy storage, sensors, and catalysis, owing to its ability to produce high-quality, uniform films with tunable properties under low processing temperatures.

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DEVELOPMENT OF AMBIENT LIGHT SENSOR MODULE FOR LINE FOLLOWER AND OBSTACLE DETECTION ROBOTS

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Abstract:

This paper presents the design, development, and implementation of an ambient light sensor module tailored for line follower and obstacle detection robots. Line follower robots are widely used in various applications, including industrial automation, surveillance, and educational platforms. To enhance their performance and versatility, incorporating an ambient light sensor module can significantly improve their capabilities for both line tracking and obstacle detection. The proposed ambient light sensor module utilizes photodetectors to measure the intensity of ambient light in the robot's surroundings. By analyzing the variations in light intensity, the module can detect changes in surface colors and differentiate between lines and their surroundings. This capability is essential for accurate line following and path tracking, enabling the robot to navigate along intricate paths with precision. Furthermore, the ambient light sensor module is also integrated with obstacle detection functionality. By evaluating light reflections and shadows, the robot can identify obstacles in its path and make real-time adjustments to avoid collisions. This additional feature enhances the safety and autonomy of the robot, making it suitable for applications in dynamic and unpredictable environments. The development process involves sensor selection, hardware integration, calibration, and algorithm implementation. The module's performance is evaluated through comprehensive testing, which includes line following accuracy and obstacle detection efficiency. Experimental results demonstrate the module's effectiveness in enabling the robot to successfully navigate complex tracks while swiftly responding to obstacles.

Keywords: Light Sensor Module, Line Follower Robot, Obstacle Detection Robot

Introduction:

A robot is an electro-mechanical machine which is generally guided by employing specific computer programs. The robot is programmed to move around in an environment such that it can suffice various purposes, such as, assisting in hotels, hospitals, airports and so on. For providing better assistance the robots must be aware of its location and the path which should be followed by the robot. So it is desirable in robots that they can detect the presence of any kind of objects, and it is further desirable to avoid any kind of coincidence with such detected objects.

The robot is configured to follow lines on a floor, or use a vision system or lasers for navigation. For example, a camera is employed with the robot, which is configured to capture the images from its surrounding and further extract a way to move onwards by comparing the captured images with the pre-stored data [1,2]. However, this approach is complex and time consuming, leading to higher possibility of collision with objects. To remove such ambiguity, the robot is employed with various sensors to obtain data about their surrounding environment, for example, a proximity sensor, optical sensor; a rotating LIDAR (light detection and ranging) sensor can be used to detect obstacles. However, the rotating LIDAR is limited in positioning on the robot, therefore not suitable for indoor purposes [3-5].

Optical sensors, such as, photodiodes and Light Dependent Resistors (LDRs), face the problem of inaccuracy due to high response time. Most of the LDRs fail to detect low light levels and have a long response time. Photodiodes, on the other hand, are temperature sensitive and unidirectional, unlike LDRs. Moreover, photodiodes tend to generate a relatively small current flow even when fully lit. Currently existing light sensing devices detect lines and nearby objects by following a dark line of about 0.75 inch width or smaller (spray paint or electrical tape) on a light background, which is less effective in direct sunlight and under infrared light. There is, therefore, felt a need for developing a path detecting system that eliminates the above-mentioned drawbacks [6-15].

The objective of this paper is to design a ambient light sensor for line following robot and to provide a path detection system for a robot that is simple, cost-effective and has quick response time.

System Model

The system comprises a line following module, and a processing unit as shown in Fig. 1. The line following module is positioned around a base of the robot. The line following module comprises at least one light source, an array of phototransistors, a comparator, and a converter. The line following module is configured to control intensity of at least one light source based on surrounding of the robot by employing PWM signal and sense the object within the range of 0.3 mm to 5 cm. For example, in ambient light during day time, the line following module turns off the light source such that a low power consumption system is obtained. The light source can be LED, infra-red LED, and laser diode and is configured to radiate one or more beams of light.

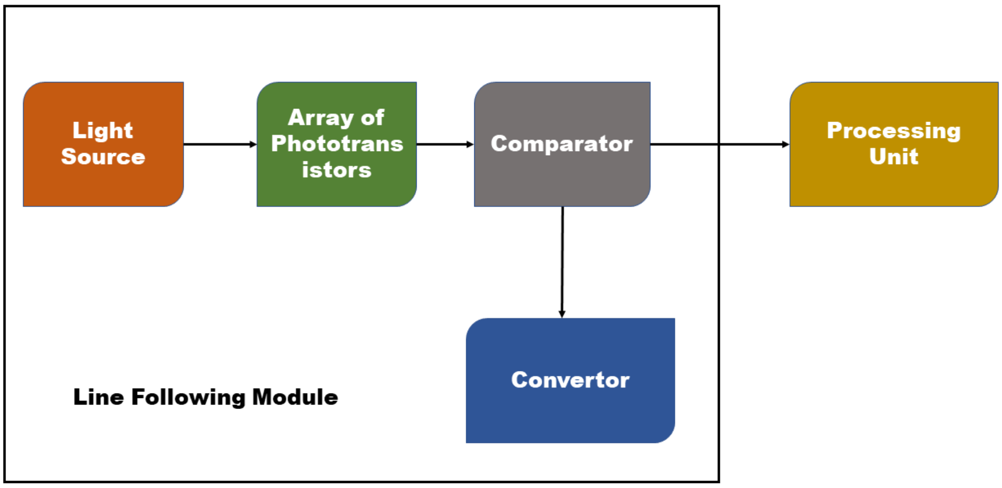


Fig. 1: System model

The array of phototransistors is configured to receive light from one or more objects in a surrounding and generate a voltage signal. The comparator is configured to receive one or more voltage signals from the array of phototransistors and to compare the voltage signal with a reference value to provide an output signal. The converter is configured to convert the output signal to a digital signal. Further, the processing unit is configured to receive the digital signal from the converter, and actuate the robot based on the digital signal. The processing unit matches a value of the digital signal in a lookup table stored in it and based on the comparison it guides the robot along a predefined path as mentioned in the flowchart (Fig. 2).

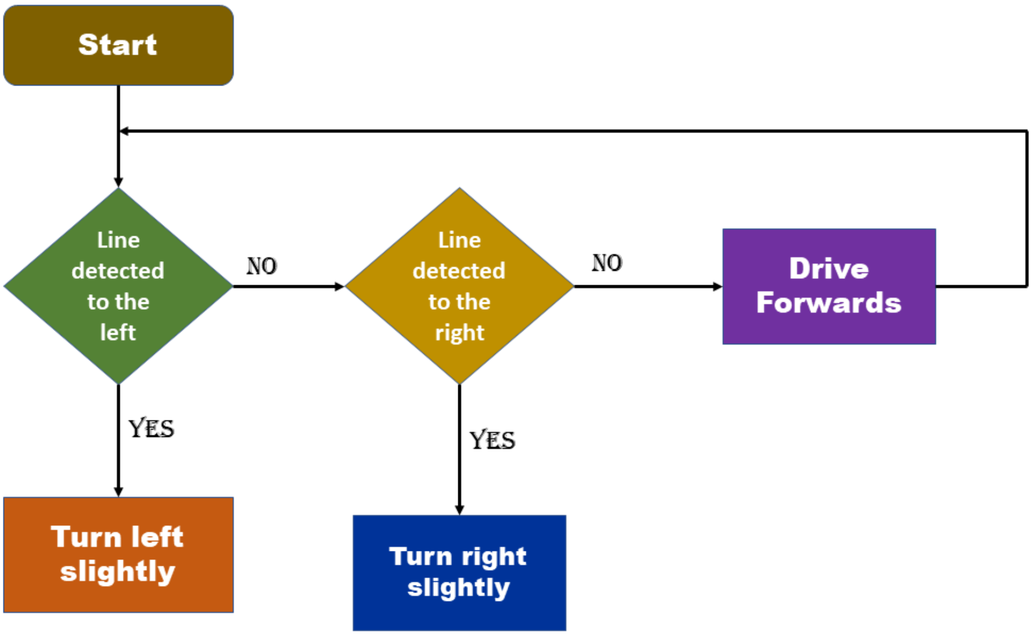


Fig. 2: Path taken by the robot

Design of Ambient Light Sensor Array

The schematic representation of light sensor module is shown in Fig. 3. Here, the Resistor R1 is connected to the phototransistor (Q1) forming a voltage divider circuit. When light falls on the base of the phototransistor current flows from the collector to the emitter (i.e., Ie = Ic + Ib, where Ic = βIb). And also, the base current is directly proportional to the intensity of light falling on the base of the phototransistor. The collector current increases with the intensity of the incident light.

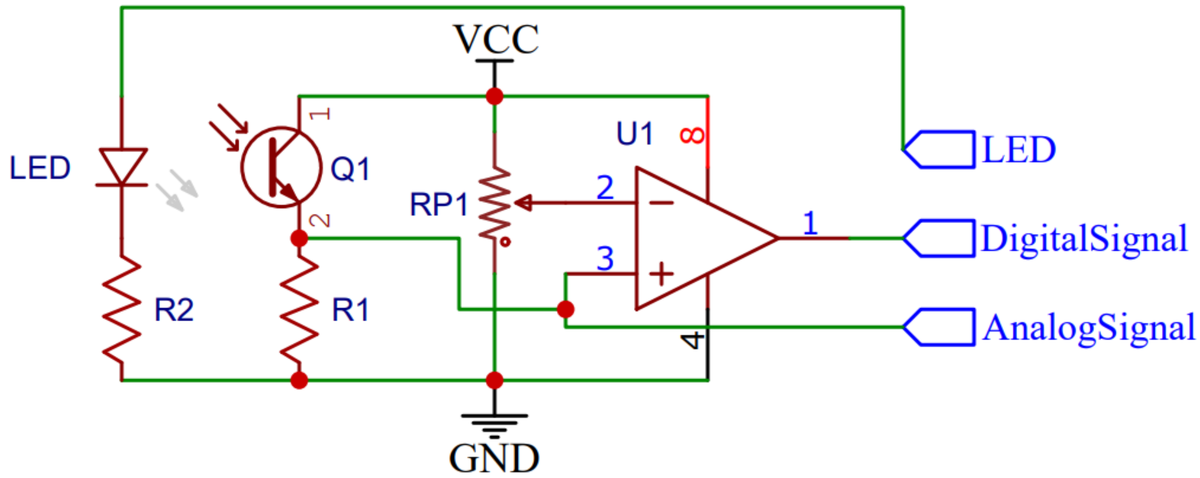


Fig. 3: Schematic representation of light sensor module

Since the resistance of R1 is constant, with the increase in collector current there will be more voltage drops across the R1. This voltage (i.e, Analog Signal) is directly proportional to the emitter current of the phototransistor Q1. This voltage drop (i.e, Analog Signal) can be directly measured using any microcontroller, simultaneously it can be fed to Comparator (U1) to obtain the digital signal. The comparator's sensitivity can be easily changed by varying the resistance of the potentiometer (RP1). The intensity of the LED can be controlled by connecting it to the microcontroller. For example, a white line on a black background surface is considered.

The white surface reflects most of the light whereas black absorbs the most.

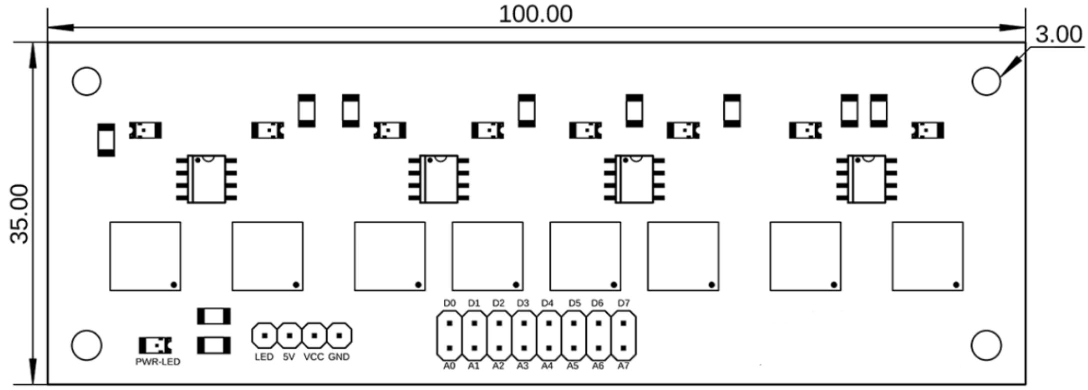
When the module with LED switched on, is brought over the white line, more light is reflected back on the base of the phototransistor and when it's brought over the black surface very low amount of light is reflected back on the base of the phototransistor. Thus for the white colour, there will be highest voltage drop (High Analog Signal), and for black there will be the lowest voltage drop (Low Analog Signal). Hence colours can be differentiated. The amount of reflection of the light on the base of the sensor would be dependent on surface, texture, color, surface reflectance, ambient light, the distance between the surface and the sensor, LED intensity, etc. For line-following robots, the resolution can be increased by using multiple light sensor modules.

Results and Discussion:

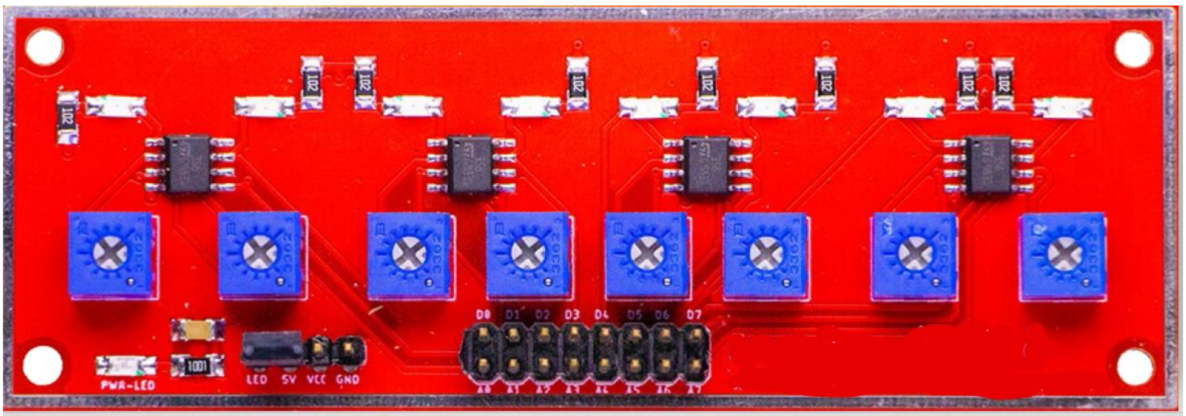
For line following robots, the ambient light sensor array with 8 LED-Phototransistor pair is a good choice because of its high precision and accuracy. In contrast to conventional line sensors, this ambient light sensor has the capability to function even at substantially higher distances above the ground.

1. Hardware Assembly

The schematic view and hardware assembly of 8 LED-phototransistor pair is shown in Fig. 4. Each LED-Phototransistor pair has its very own Digital and Analog output. While the analog output pins can be directly plugged into the microcontroller of one's choice and used to take analog readings, each of the digital outputs is equipped with a potentiometer which can be used to adjust sensitivity based on distance from surface or colour difference which can be visually inspected through the indicator LED present for each LED-Phototransistor pair on the top of the sensor array.



(a)



(b)

Fig. 4: Eight LED-Photo transistor pair ambient light sensor array (a) schematic view (b) Hardware assembly

2. Obtained Results

The brightness of the LEDs can be controlled by applying analog voltage of 0V to 5V at the LED pin on the sensor or applying high-frequency PWM at the LED pin on the sensor. Hence the user can even turn off the LEDs fully when required which also lowers the overall power consumption. The line sensor is also capable of delivering consistent output even on glossy surfaces which is usually not possible or difficult in IR based line sensors. This ambient light sensor is highly capable of generating adequate analog difference between any two colours, unlike other sensors which only produce a precise analog difference between black & white but fail to properly differentiate between different colours.

The designed ambient light sensor has the dimension of 100 mm × 35 mm and can operate in the voltage range of 4.5 to 5.5 V (Nominal 5V). It has the sensing distance of 3 mm to 50 mm. The results obtained from the proposed design for a line following and obstacle detection robots is shown in Fig. 5.

Fig. 5: Results Obtained from Line follower Robots mounted with Designed Light Sensor Module

Conclusion:

The developed ambient light sensor module offers an innovative solution for improving the capabilities of line follower robots. Its dual functionality for line tracking and obstacle detection presents a versatile platform that can be employed in various practical scenarios. The integration of this module empowers robots with enhanced autonomy, making them valuable tools for industries and educational purposes alike.

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MYRTACEAE FAMILY: UNVEILING ITS DIVERSE SPECIES, USES, AND CONSERVATION CHALLENGES

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Introduction:

The Myrtaceae family, commonly known as the myrtle family, is a stunning exemplar of biodiversity, boasting an impressive range of species, a testament to nature's ingenuity. The distinctive aroma of arises from the presence of essential oils stored in specialized structures, such as oil glands in their leaves, flowers, bark, and fruits. These essential oils are complex mixtures of volatile organic compounds, primarily terpenes and phenolic compounds. This aromatic trait not only defines the Myrtaceae family but also makes its members valuable for essential oil production, traditional medicine, and culinary uses. So it is of no wonder to say that Myrtaceae plants are important not only for their medicinal and economic benefits but also for their contributions to biodiversity and environmental sustainability. This comprehensive overview explores the intricacies of Myrtaceae, shedding light on its diverse applications and the pressing challenges it faces.

The family, comprising over 6,000 species, is a vibrant and diverse group of plants. When morphological characters were considered, most species are evergreen shrubs or trees with simple, opposite, or alternate leaves, containing essential oil glands, visible as small dots when held up to light. The flowers are typically bisexual and actinomorphic (radially symmetrical). The noteworthy feature of Myrtaceae flower is the showy with numerous stamens, making the most conspicuous part of the flower. The flowers are also aromatic due to essential oils. The fruits are berries, capsules, or drupes, often containing numerous seeds.

Pharmaceutics and Therapeutics

The Myrtaceae family has been a treasure trove of bioactive compounds, offering a wide range of pharmaceutical applications. Modern research validates the traditional uses of these plants, revealing their potential in healthcare and wellness. The essential oils found in leaves, bark, flowers, and fruits, essential oils are a defining characteristic of the Myrtaceae family. 1,8-cineole (eucalyptol) found in Eucalyptus species is a versatile phytochemical with various therapeutic potentiality like antimicrobial, anti oxicant, expectorant, anti-inflammatory, and anticancer activity (Hoch *et al.,* 2023). Euginol, is weak acidic phenolic volatile compound found in *Syzygium aromaticum* (Clove) is used for analgesic and antiseptic purpose (Haro-González etal., 2021). Terpinen-4-ol from tea tree (*Melaleuca alternifolia*) oil is best known for its antimicrobial activity. α and β pinenes are representatives of the monoterpenes group and are found in Melaleuca and Eucalyptus (Salehi *et al.,* 2019). A wide range of pharmacological activities have been reported, including anticoagulant, antioxidant and antibiotic resistance modulation. The phenolic compounds considered to be responsible for antioxidant and antimicrobial activities. The gallic acid found in *P. guajava* has a powerful antioxidant and antimicrobial agent (Pereira *et al.,* 2023). Similarly, the ellagic acid found in the fruits of Guava shows anticancer potential (Lok *et al.,* 2023). The flavonoids like quercetin and kaempferol showed anti-inflammaoty and cardioprotective activities. The presence of tannin proved the astringent and antimicrobial potential for the leaf and bark of Guava, hence used to treat diarrhea and wounds. In Myrtus species, the terpenoid called limonene (Aleksic & Knezevic, 2014) is present that has mood-enhancing effect, while myrcene, another terpenoid found in Eucalyptus provide analgesic property. The immune boosting action of *P. guajava* is due to the presence of saponins. Though less common, some myrtaceae members like Eugenia and Syzygium, produce alkaloids β-caryophyllene in Syzygium species (Rameshkumar *et al.,* 2015) and chlorogenic acid in Eucalyptus offer antioxidant and anti-inflammatory benefits to the plants.

Recent pharmacological research on the Myrtaceae family highlights significant findings related to antimicrobial, anticancer, antioxidant, and anti-inflammatory properties, as well as potential applications in drug development. Essential oils and extracts from species like *Eucalyptus* and *Syzygium* demonstrate potent antibacterial effects, particularly against multi-drug-resistant (MDR) pathogens causing respiratory infections (Khan *et al.,* 2009). Terpenoids and phenolic compounds are key contributors to their antimicrobial efficacy. Research also suggests that bioengineered nanoparticles using Myrtaceae extracts enhance antibacterial activity through improved cellular penetration (Garcia *et al.,* 2023). Certain Myrtaceae compounds, including isolated from *S. aromaticum* inhibits HeLa cancer cell migration by altering epithelial-mesenchymal transition protein regulators eugenol (Permatasari *et al.,* 2021). Studies have explored their role in apoptosis induction and cell cycle modulation in various cancers, making them promising candidates for anticancer therapy. Advances in nanotechnology are integrating Myrtaceae-derived bioactives into innovative delivery systems, such as nanoparticle formulations, enhancing their bioavailability and therapeutic effects (Chavda *et al.,* 2022). These findings suggest that the Myrtaceae family holds great promise for developing new pharmaceutical agents, addressing challenges like drug resistance and chronic diseases.

Some members of the Myrtaceae family have shown potential for addressing viral infections like COVID-19, SARS, and other similar conditions, though more research is needed for conclusive therapeutic applications. Compounds like eucalyptol (from *Eucalyptus spp.*) have demonstrated antiviral properties (Mieres-Castro *et al.,* 2021), including potential inhibition of SARS-CoV-2 replication and anti-inflammatory effects, making them candidates for managing COVID-19-related cytokine storms. However, clinical validation is still in progress. Studies suggest that bioactive photochemical from plants, including those in Myrtaceae, can target viral proteins like spike glycoprotein and enzymes essential for viral replication. However, no Myrtaceae-derived compound has yet been established for SARS-CoV or MERS. While antiviral activities of Myrtaceae species have been studied for general retroviral infections, their specific efficacy against HIV remains largely unexplored. Some extracts exhibit immune-boosting properties, which could indirectly benefit patients.

Economic Viability of Myrtaceae

The Myrtaceae family is economically significant due to its diverse uses in horticulture, forestry, agriculture, and medicinal industries. Many species are valued for their aromatic essential oils, extracted from leaves, fruits, or bark. Eucalyptus is used in medicines, cosmetics, and disinfectants. Clove is used as a spice, in perfumes, and in medicinal applications. Tea tree is known for its antifungal and antibacterial properties in skin care products. The family includes several plants cultivated for their edible fruits. Guava is a rich source of vitamin C and widely consumed fresh or processed into juices and jams. Myrtle fruits are used in liqueurs and as a spice. The rose apple java apple and wax apple are consumed fresh or used in cooking. The timber of Eucalyptus is used for construction, furniture making etc. Many Myrtaceae members are grown for their aesthetic appeal, thanks to their attractive flowers, foliage, and overall form. Besides the medicinal use Myrtaceae plants play a vital role in ecosystems. Eucalyptus species are used in soil stabilization and erosion control. Many species are drought-resistant, making them suitable for reforestation in arid areas. Myrtle and clove are used in alcoholic beverages like liqueurs (Manjusha *et al.,* 2022), while guava is a popular ingredient in juices and desserts. So, it is proved that the Myrtaceae family is indispensable for its contributions to food, medicine, industry, and ecology, making it a highly versatile and valuable plant family.

Major Threats

Myrtaceae plants are facing several significant threats. Regional threats and conservation status vary, with Australian species facing myrtle rust and climate change, while South American species are threatened by deforestation. Myrtle rust, a fungal disease caused by *Austropuccinia psidii*. This disease has spread across various regions, particularly in Australia (Tobias *et al.,* 2021), where it affects numerous species within the family, including eucalypts, guavas, and tea trees. Myrtle rust damages plant growth, disrupts reproduction, and is causing a rapid decline in some species, such as the native guava (*Rhodomyrtus psidioides*), which is now nearly extinct in the wild due to this disease. In addition to myrtle rust, these plants are also vulnerable to climate change, which exacerbates environmental stresses, and deforestation, which destroys their habitats. In South American regions, Myrtaceae plants threatened by deforestation and habitat fragmentation, while in Southeast Asian countries, the family is vulnerable to over-exploitation and invasive species. To mitigate these threats, sustainable practices, conservation breeding programs and disease management, habitat protection, and education are crucial for preserving these valuable plants.

Conclusion:

In summary, the Myrtaceae family's rich biodiversity and multifaceted applications make it an indispensable part of our planet's ecosystem. By addressing the challenges facing this family and promoting conservation, sustainable practices, and scientific inquiry, we can ensure the continued provision of its ecological, medicinal, and economic benefits. So we must prioritize conservation and sustainable practices to ensure the continued benefits of Myrtaceae species.

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UNVEILING THE SCIENCE OF DISASTER RECOVERY: BUILDING A RESILIENT FUTURE

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Abstract:

The importance of infrastructure for supply chain management, logistics, and the delivery of essential products and services has been brought to light by the COVID-19 epidemic. It has brought attention to the need for nations to strengthen its infrastructure to withstand future pandemics and disasters and to guarantee the survival of vital networks like transportation and telecommunications. While promoting sustainability, the development of green infrastructure may provide protection against the consequences of climate change and the environment. Disaster resilience and recovery are essential components of a community's capacity to recover from adverse events. Successful efforts include forethought, community involvement, and the use of cutting-edge technologies. Disasters can have a big influence on a community's way of life, means of sustenance, and long-term growth. Events related to hydrometeorology are the main cause of calamities, and disaster risk is an increasing worldwide issue. This paper emphasizes the use of a tactical and systematic approach to observe and prepare for disasters for lowering the risks and susceptibility to hazards.

Keywords: Resilience; Green Infrastructure; Hazards; Sustainable Development Goals; Environmental Sustainability, Disaster Risk Reduction.

Introduction:

Disasters are significant setbacks that a community cannot handle alone, resulting from natural, man-made, and technical risks. They have severe consequences for people's lives, livelihoods, and development benefits. Disaster risk is a combination of physical, social, economic, and environmental vulnerabilities. Most disasters are caused by hydro-meteorological events. Despite increasing global concern over disaster risk, disaster management and risk reduction remain a global challenge. Communities are impacted by disasters in various ways, including exceeding individual and communal capacity, destroying resources, upsetting relationships, endangering safety, and overwhelming community capacity to meet physical and emotional needs. Most traumatized individuals do not experience PTSD, but most can navigate initial adaptive phases without succumbing to long-term progression. Resilience and sustainability are crucial aspects of Critical Infrastructure Protection (CIP), which has gained public and governmental attention in recent decades. As societies become more complex and interconnected, programs and initiatives are being launched to safeguard vital societal functions.

Disaster Resilience

Disaster resilience and recovery are crucial for a community's ability to withstand and recover from adverse events. Resilience involves building robust systems and infrastructure to absorb shocks and maintain essential functions during a disaster, while recovery focuses on restoring normalcy after an event. Effective strategies involve proactive planning, community engagement, and the integration of innovative technologies. By investing in these measures, societies can minimize disaster impacts, enhance recovery speed, and create more sustainable environments. Disaster resilience is measured by how well people, communities, and organizations can learn from past disasters and reduce future chances. Building disaster-resistant communities involves organizational, legal, and regulatory frameworks, risk identification, assessment, monitoring, early warning, knowledge management, reducing risk factors, and preparedness for efficient reaction and recovery. The essential components of disaster resilience (as shown in Figure 1.) are situation, trouble, response capacity, and reaction.

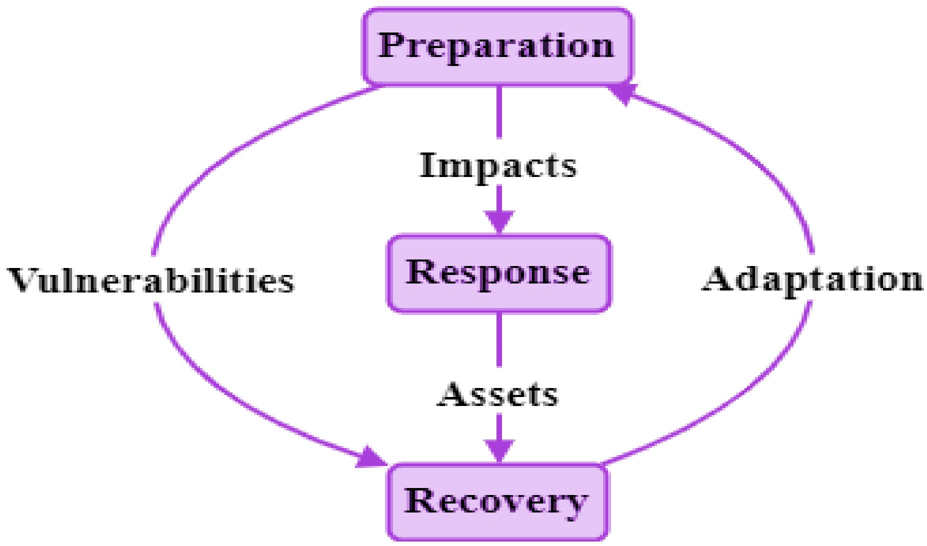

Fig. 1: Essential components of disaster resilience

- **Situation**: The social group, socioeconomic system, political structure, environmental situation, or institution whose resilience is being built.
- **Trouble**: What shocks (sudden occurrences like violence or disasters) and/or pressures (long-term trends like resource degradation, urbanization, or climate change) the group seeks to be robust to?

- **Response capacity:** The capacity of a system or process to respond to a shock or stress depends on exposure (the size of the shock or stress), sensitivity (the extent to which a system will be affected by, or will respond to, a given shock or stress), and adaptive capacity (how well it can adapt to a disturbance or moderate damage, take advantage of opportunities, and deal with the effects of a transformation).
- **Reaction**: A variety of reactions are possible, including rebound better, where capacities are improved, exposures are decreased, and the system is better able to handle upcoming shocks and stresses; rebound, where pre-existing conditions prevail; or rebound, but worse than before, where capacities are diminished. In the worst-case scenario, the system fails, drastically reducing our ability to handle the future.

Disaster Risk Management

Disaster risk management is the use of policies and techniques for reducing disaster risk to prevent new disaster risks, lower current disaster risks, and manage residual risks. This helps to increase disaster resilience and cut down on disaster losses. The core principles of disaster risk management are to actively participate and take a proactive approach to reducing vulnerability, enhancing capacity, and improving catastrophe resilience. The idea of a risk society is a crucial topic within the context of disaster risk reduction and disaster resilience. Eliminating vulnerabilities and managing risk are inextricably tied to resilience, especially in the context of calamity training. The approach to disaster risk management used by local and indigenous peoples involves acknowledging and utilizing traditional, indigenous, and local knowledge and practices as a supplement to scientific knowledge in disaster risk assessments and for the planning and execution of local disaster risk management.

Future disaster risk management initiatives deal with and try to prevent the emergence of new or elevated disaster risks. They concentrate on resolving potential disaster hazards that could arise later if disaster risk reduction strategies are not implemented. Better land use planning or water supply systems that can withstand disasters are two examples. Corrective disaster risk management initiatives target existing catastrophe risks that need to be managed and diminished right now and aim to eliminate or minimize them. Examples are the retrofitting of critical infrastructure or the relocation of exposed populations or assets.

Disaster risk management plans set out the goals and specific targets for decreasing catastrophe risks coupled with relevant measures to fulfil these objectives. They should be guided by the Sendai Framework for Disaster Risk Reduction 2015-2030 and considered and coordinated within relevant development plans, resource allocations, and program activities. Plans at the national level must be tailored to each level of administrative responsibility as well as the various social and geographic conditions that exist. The implementation schedule, roles, and sources of funding should all be laid out in the plan. Linkages to sustainable development and climate change adaptation plans should be made where possible. The inclusion of potentially affected communities in local disaster risk management is encouraged by community-based disaster risk management. This comprises assessments of risks, weaknesses, and capacities made by the local community, as well as their participation in local disaster risk reduction planning, implementation, monitoring, and evaluation.

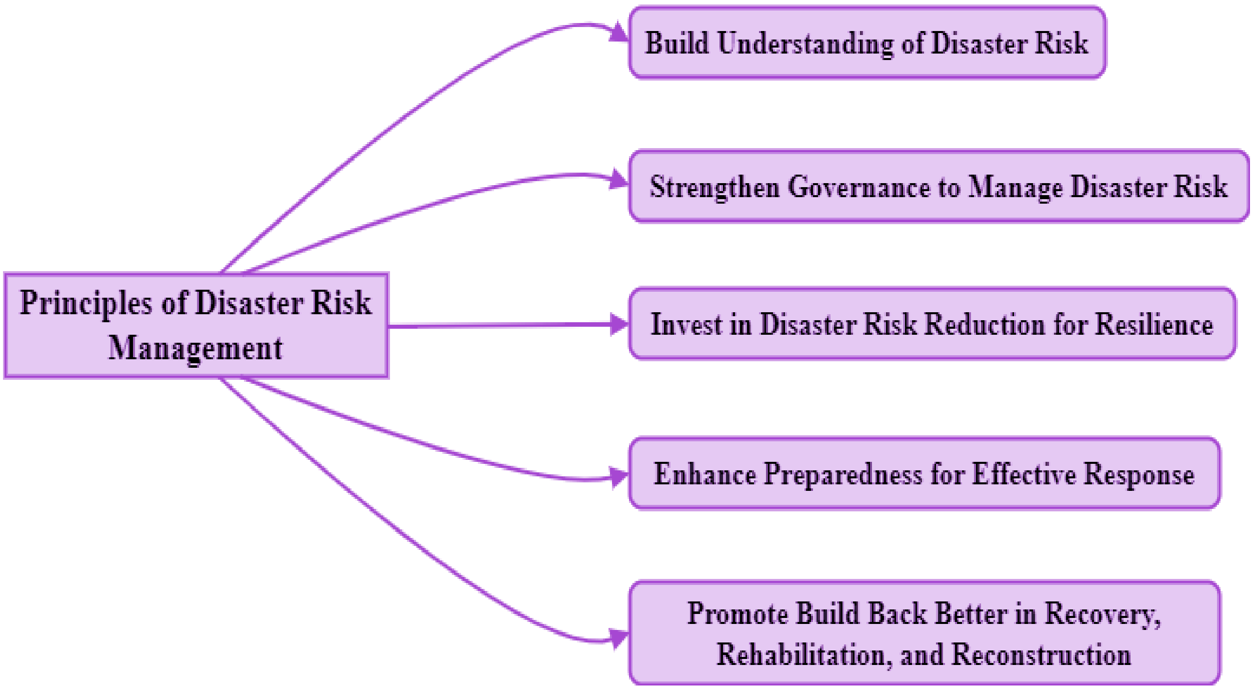

Fig. 2: Core Principles of Disaster Risk Management

The Science of Disaster Recovery

The science of disaster recovery is a multidisciplinary approach involving engineering, meteorology, sociology, psychology, and urban planning. It involves developing strategies for efficient community recovery, using advanced technologies, data analytics, and modeling. Engineering designs, meteorological forecasting, and social sciences help create targeted recovery plans. The field is evolving with innovations like artificial intelligence, machine learning, and remote sensing, enabling early detection and adaptive recovery strategies.

Building a Resilient Future

Building a resilient future requires a holistic and forward-thinking approach that addresses the challenges posed by a changing environment, emerging risks, and the interconnected nature of our world. Resilience involves enhancing the ability of individuals, communities, and systems to anticipate, prepare for, respond to, and recover from shocks and stresses. Building a resilient future involves several key components, including thorough risk assessment and planning, infrastructure resilience, community engagement and empowerment, technological innovation, climate change adaptation, education and training, and global cooperation. Risk assessments help identify potential hazards and vulnerabilities, while infrastructure resilience involves designing and constructing resilient buildings, transportation systems, and utilities to ensure continuity of essential services. Community engagement fosters ownership and cooperation, while technological advancements like early warning systems, smart infrastructure, and data analytics enhance disaster prediction and recovery. Climate change adaptation involves implementing sustainable practices, promoting renewable energy sources, and adapting to changing environmental conditions. Education and training on disaster preparedness, first aid, and evacuation procedures are essential for individuals and communities.

Emergency Preparedness

Emergency preparedness involves a series of steps: prevention, mitigation, preparedness, response, and recovery. The "Prevention/Mitigation" phase involves actions to prevent or lessen damage, such as building flood-protective dams and dikes. "Preparedness" involves activities to ensure an effective reaction to hazards, such as emergency exercises and public awareness campaigns. These steps improve a community's capacity to react in the event of a disaster. "Response" involves actions like rescue missions, first aid, firefighting, and evacuation. Sharing preparedness plans makes it easier to execute plans in an emergency case. Actions are taken immediately to preserve lives, minimize financial losses, and ease suffering. "Rehabilitation/Reconstruction" involves actions to restore basic services and fix physical, social, and economic damages. Recovery measures include rebuilding roads, bridges, and important facilities, debris clean-up, and continued mass care for displaced people and animal populations. NGOs offer significant aid in emergency relief, shelter, and livelihood support. These steps help communities return to normal or almost normal conditions, ensuring a smooth transition to normal life. The overall disaster risk can be decreased by adopting appropriate measures based on the disaster risk management concept in each phase of the disaster risk management cycle, as shown in Table 1.

Table 1: Measures in Each Disaster Risk Management Phase

Disaster Type	Mitigation Techniques
Earthquakes	- Seismic-resistant building design
	- Early warning systems
	- Land-use planning to avoid vulnerable areas
	- Community drills and education
Floods	- Floodplain mapping and zoning
	- Construction of levees and dams
	- Early warning systems
	- Sustainable water management practices
Hurricanes/Cyclones	- Storm-resistant building codes
	- Coastal vegetation restoration
	- Evacuation planning and drills
	- Improved weather forecasting
Wildfires	- Defensible space around structures
	- Controlled burns for vegetation management
	- Firebreaks and fuel management
	- Community education on fire prevention
Tornadoes	- Construction of tornado shelters
	- Early warning systems
	- Adoption of building codes for tornado-prone areas
	- Public awareness campaigns
Tsunamis	- Tsunami-resistant building design
	- Early warning systems with sirens and alerts
	- Coastal land-use planning and zoning
	- Evacuation drills and community education
Pandemics	- Vaccination programs
	- Quarantine and isolation measures
	- International cooperation on disease control
	- Public health campaigns and awareness

Disaster Recovery Process

The disaster recovery process is a series of coordinated activities aimed at rebuilding and restoring affected areas after a disaster. It is crucial for minimizing the impact, restoring normalcy, and enhancing community resilience. The process includes assessment and planning, emergency response and stabilization, resource allocation and funding, infrastructure rehabilitation, economic recovery and stimulus, social services and welfare, environmental restoration, community engagement and participation, risk reduction and preparedness, monitoring and evaluation, documentation and knowledge sharing, and long-term resilience building.

Assessment and planning involve evaluating the damage caused by the disaster, identifying goals, strategies, and resource requirements. Emergency response efforts focus on saving lives, providing shelter, medical care, and ensuring public safety. Resource allocation and funding are critical steps, with governments, NGOs, and other stakeholders contributing funds for immediate relief and long-term recovery. Infrastructure rehabilitation involves rebuilding and repairing critical infrastructure to restore essential services, facilitate economic activities, and enhance community resilience against future disasters. Economic recovery plans, including stimulus packages and support for businesses, aim to revitalize the local economy, create jobs, and help affected businesses and industries recover. Social services and welfare address immediate needs and support long-term recovery, such as housing assistance, counseling services, healthcare access, and education programs. Environmental restoration involves mitigating damage to ecosystems, promoting sustainable practices, and preventing future degradation. Community engagement and participation in the recovery process helps understand specific needs, cultural considerations, and build a sense of ownership. Continuous monitoring and evaluation assess the effectiveness of implemented measures, while documentation and knowledge sharing contribute to future disaster preparedness and recovery efforts.

Role of Government Agencies and Organizations in Facilitating Recovery

Government agencies and organizations play a crucial role in facilitating recovery in various contexts, including economic, social, and environmental recovery. They involve planning, implementing, and coordinating efforts to address challenges, crises, or disasters. Key aspects of their roles include policy development and regulation, coordination and collaboration, resource allocation and funding, infrastructure rehabilitation, public health and safety, economic stimulus and development, social services and welfare, environmental conservation and restoration, information dissemination and communication, risk reduction and preparedness, legal and regulatory frameworks, and international cooperation. Policy development and regulation involve formulating policies that guide recovery efforts, covering areas such as economic stimulus, public health, infrastructure development, and environmental conservation. Coordination and collaboration among government agencies, NGOs, international bodies, and community groups ensure a comprehensive and unified approach to recovery.

Resource allocation and funding are essential for supporting recovery initiatives, including financial assistance to individuals, businesses, and communities affected by crises or disasters. Government agencies are responsible for rebuilding and rehabilitating critical infrastructure, managing public health concerns during recovery, implementing economic recovery plans, providing social services and welfare, and focusing on environmental conservation and restoration. Information dissemination and communication are vital for managing public expectations, providing guidance on recovery measures, and enhancing community resilience. Government agencies also work on long-term strategies for risk reduction and preparedness, investing in infrastructure resilience, early warning systems, and community education. Legal and regulatory frameworks are established to facilitate recovery, including insurance, property rights, and land use planning. International cooperation is also sought to enhance recovery capacity, enabling the sharing of expertise, resources, and best practices.

Importance of Reducing the Risk of Disaster

Disaster risks have an impact on people's lives, livelihoods, and health as well as on the physical, mental, cultural, and environmental health of people, groups, and nations. Disasters significantly impede progress toward sustainable development, many of which are exacerbated by climate change and are increasing in frequency and intensity. Therefore, disaster risk reduction not only saves lives but also promotes the well-being of people and communities. To work with communities at risk of catastrophe to create DRR practices and lessen the risks posed by upcoming disasters, using the criteria provided by the United Nations International Strategy for Catastrophe Response (UNISDR). The process of reorientation highlights the crucial value of location, not only as a framework for recovery but also as the foundation for the development of social capital and community disaster resilience. Community psychologists and other service providers working to support disaster survivors should consider the implications of this method of comprehending and addressing the disorientation caused by disasters.

Role of Education and Awareness in Building Resilience

Education and awareness are essential for building resilience at individual, community, and societal levels. They enhance knowledge, foster preparedness, and promote proactive behaviors, contributing to a more adaptive response to challenges like natural disasters and climate change. Key aspects of education include risk understanding, preparedness and emergency response, climate change awareness, community engagement, health and hygiene practices, technology and information access, crisis communication skills, economic resilience, cultural competence and inclusivity, lifelong learning and adaptability, environmental stewardship, policy advocacy, and civic engagement.

Risk understanding helps individuals and communities understand the risks they face, enabling better planning and preparedness. Emergency preparedness includes evacuation procedures, first aid, and disaster response strategies. Climate change awareness raises awareness about climate change's potential impacts, preparing communities to adapt to changing environmental conditions and engage in sustainable practices. Community engagement encourages individuals to actively participate in resilience-building efforts, fostering collaboration and knowledge sharing.

Health and hygiene practices improve resilience by providing knowledge about disease prevention, sanitation, and healthcare access. Technology and information access facilitate access to information, enabling communities to stay informed about potential risks and receive real-time alerts. Crisis communication skills develop during crises, coordinating responses, disseminating information, and maintaining order. Economic resilience is enhanced by financial literacy and sustainable economic practices. Cultural competence and inclusivity ensure that resilience-building efforts consider diverse perspectives, needs, and vulnerabilities within a community.

Common Challenges Faced During Disaster Resilience and Recovery

Disaster resilience and recovery are complex processes involving numerous challenges faced by communities, governments, and organizations. Common challenges include limited resources, infrastructure damage, complex decision-making, community displacement, economic impact, social and psychological impact, environmental concerns, policy and regulatory issues, inequality and vulnerability, communication and information gaps, climate change adaptation, interconnected risks, long-term planning vs. immediate needs, coordination and collaboration among stakeholders, and political will and governance.

Limited resources can hinder effective recovery efforts, as communities may struggle to access the necessary funds and expertise. Infrastructure damage can be time-consuming and resource-intensive, making it difficult to rebuild structures. Decision-making during recovery requires balancing short-term and long-term needs, considering competing interests and the diverse needs of affected populations. Community displacement poses a pressing concern, as providing adequate housing, services, and support for displaced populations is crucial. Economic impacts, such as job loss and local economies revival, must be addressed. Social and psychological impacts, such as mental health issues, trauma, and community cohesion, are also essential for holistic recovery.

Table 2 shows the common challenges faced during disaster resilience and recovery.

Table 2: Common Challenges Faced During Disaster Resilience and Recovery

Challenge	Description
Limited Resources	Scarce financial, human, and material resources can hinder effective recovery efforts.
Infrastructure Damage	Extensive damage to infrastructure, such as roads and buildings, can impede recovery.
Complex Decision-Making	Decision-making during recovery is complex, involving trade-offs and balancing diverse needs.
Community Displacement	Displacement of communities due to disasters poses challenges in providing adequate housing.
Economic Impact	Disasters have severe economic consequences, affecting businesses, industries, and employment.
Social and Psychological Impact	Disasters can have lasting social and psychological effects, requiring mental health support.
Environmental Concerns	Environmental damage from disasters, such as pollution, poses challenges for recovery.
Policy and Regulatory Issues	Inadequate or conflicting policies and regulations can impede recovery efforts.
Inequality and Vulnerability	Existing social inequalities can exacerbate vulnerability during and after disasters.
Communication and Information Gaps	Gaps in information dissemination can lead to confusion and hinder coordinated responses.
Climate Change Adaptation	Adapting to climate change impacts requires long-term planning and investment.
Interconnected Risks	Disasters can lead to cascading effects and interconnected risks that complicate recovery.
Long-Term Planning vs. Immediate Needs	Balancing immediate needs with long-term planning is a challenge in the recovery process.
Coordination and Collaboration	Effective coordination among various stakeholders is crucial for successful recovery.
Political Will and Governance	The political will to implement and sustain recovery initiatives is critical for success.

Policy and regulatory issues can impede recovery efforts, and ensuring policies align with recovery goals is crucial. Existing social inequalities can exacerbate vulnerability during and after disasters, highlighting the need for equitable recovery strategies. Effective communication and information dissemination are crucial during recovery, but gaps in information dissemination can lead to confusion. Climate change adaptation measures must be integrated into recovery plans due to the increasing frequency and intensity of disasters linked to climate change. Navigating these challenges requires a comprehensive and collaborative approach, focusing on building adaptive capacities, addressing vulnerabilities, and promoting sustainable practices for long-term resilience.

Importance of Long-Term Planning and Investments In Resilience

Long-term planning and investments in resilience are essential for communities, regions, and nations to prepare for and respond to various challenges, such as natural disasters, climate change, and socio-economic disruptions. These efforts involve risk reduction and mitigation, sustainable development, community empowerment, adaptive capacity, economic stability, infrastructure resilience, climate change adaptation, public health preparedness, education and awareness, reduced recovery costs, insurance against future risks, social cohesion and equity, government and institutional resilience, and international cooperation and diplomacy. Risk reduction and mitigation strategies help minimize the impact of disasters and other adverse events, reducing the likelihood of extensive damage and loss. Sustainable development practices, such as sustainable infrastructure, land use planning, and resource management, contribute to long-term environmental, social, and economic stability. Community empowerment fosters self-reliance and community cohesion.

Investments in resilience enhance adaptive capacity, allowing systems or communities to adjust to changing conditions more efficiently. Economic stability is maintained through long-term investments in economic diversification, job creation, and business continuity planning. Infrastructure resilience ensures systems can withstand shocks and function effectively, while climate change adaptation involves investments in measures like sea-level rise mitigation, water resource management, and sustainable agriculture practices. Education and awareness initiatives support communities in understanding potential risks and preparedness measures. Long-term planning also reduces recovery costs, insurance against future risks, and promotes social cohesion and equity.

Role of Technology in Improving Disaster Resilience and Recovery Efforts

Technology plays a pivotal role in enhancing disaster resilience and recovery efforts by providing innovative solutions for preparedness, response, and rebuilding. Advanced data analytics, remote sensing, and geographic information systems (GIS) enable accurate risk assessments, allowing communities to proactively plan for potential disasters. Communication technologies facilitate real-time information dissemination, aiding swift emergency responses. Drones and satellite imagery assist in assessing damage, while predictive modelling enhances early warning systems. Mobile applications empower communities with disaster preparedness information, and social media platforms serve as crucial communication channels during crises. Additionally, cloud computing and data storage enhance collaboration among stakeholders, facilitating efficient resource allocation. In the recovery phase, technologies like 3D printing and artificial intelligence streamline reconstruction processes. Overall, technology plays a transformative role in building resilience and fostering more effective responses to disasters.

Conclusion:

Policies aimed at reducing poverty and promoting sustainable development must include disaster risk mitigation strategies, backed by local and national partnerships and cooperation. In order to become more robust to natural catastrophes, these initiatives must concentrate on general development, poverty reduction, and information exchange. It is the duty of people, local governments, states, and federal government agencies to manage emergencies. Communities that possess resilience skills are better able to respond and recover. Operational public health practice actions must be aligned with federal policy objectives, such as the Federal Emergency Management Agency's "Whole of Community Planning" mandate and the CDC's community preparation guidelines. Health departments need to update internal protocols and establish a framework for community-level cooperation that is founded on precisely specified programming goals. Building resilience requires knowledge and awareness to equip people and communities with the abilities to adapt to changing circumstances and bounce back from setbacks. Incorporating community participation with educational endeavours results in a future that is more sustainable and resilient.

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DETERMINATION OF CRYSTAL STRUCTURE AND ELASTIC CONSTANTS OF MCU-5 COTTON FIBER USING WAXS DATA

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Abstract:

Wide-angle X-ray scattering (WAXS) for the considered MCU-5 cotton fiber has been carried out. By employing Linked atom least square (LALS) method, we are reporting here the molecular and crystal structure of this cotton fiber. We have computed elastic moduli tensor components of these fibers.

Keywords: Elastic Constants; WAXS; LALS; MCU-5

Introduction:

One of the widely used natural fiber is cotton. It belongs to a family Malvaceae and genus Gossypium. Cotton is essentially pure cellulose and a high polymer consisting of units of anhydro-glucopyranose linked through β-1-4 linkages with its empirical formula $(C_6H_{10}O_5)_n$. The elastic constants of cellulose were computed by assuming molecular models of jaswan (Jaswan et al 1968). By using two different sets of hydrogen bond force constants of 24.6 and 31.9 $\times 10^{10}$ N/m^2, the young's modulus has been estimated along the chain direction (Gillis 1969). We have also investigated the crystal structure features of these fibers using linked atom least square (LALS) technique. The elastic tensor components of these fibers were determined using Treloar (1960) equations and structural data, which we have determined by LALS technique here.

Materials and Methods

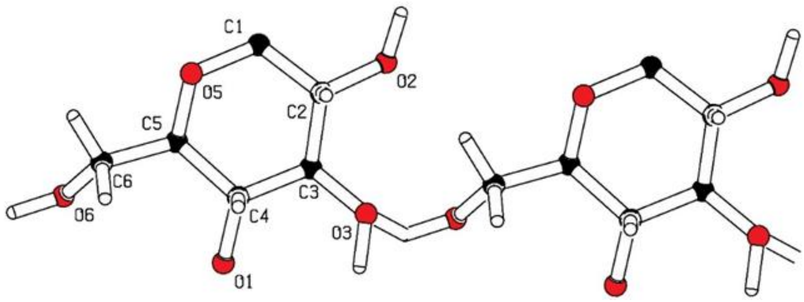
1. Preparation of Sample

MCU-5 is a cross breed developed from Sea Island, 542, MCU 1, MCU 2 and Gatooma [12]. We have plucked raw MCU-5 cotton fiber after ripening. This cotton is freed from the buds and taken it for ginning then it is taken for baling till it becomes as lint. The lint raw cotton sample is used for our study without any additional treatment.

2. X-ray Diffraction Studies

The samples were made into small bundles and clamped into a sample holder which was then mounted on the goniometer such that the rotational axis was parallel to the fiber axis and perpendicular to the X-ray beam. Here, we used an imaging plate system (DIP-3200) with dimensions 440 x 240 mm^2, which was moved parallel to the axis of rotation. The wavelength of X-ray radiation was 0.71073Å (Mo target). The X-ray generator (RIGAKU) settings used were 50 kV and 32 mA. The time of exposure was kept at 400s. Equatorial scans of intensity verses 2θ were carried out using the MOSFLM software supplied with instrument. The X-ray diffraction pattern recorded for the different samples from the imaging plate system was converted to the line profile format.

Linked Atom Least Squares (LALS) program



With the development of computer-based physical modeling the molecular and crystal structure was generated by using LALS method (Smith and Arnott, 1978) and the computations and compilations were carried out using a Linux based PC. Actually there is a method to pack the two polymer chains with 2/1-helical symmetry in a unit cell with space group P2$_1$.

Table 2: Final model parameters of cellulose for MCU-5 cotton fiber after several refinements using experimental intensities

Torsion angles at glycosidic linkage (deg)		Glycosidic angle (deg)	
ϕ(C2-C1-O1-C4)	62.80°	τ(C1-O1-C4)	22.76°
Ψ(C1-O1-C4-C3)	-66.52°	Orientation of O6 (deg)	
Eulerian angles (deg)		χ(O5-C5-C6-O6)	141.08
ε_x	103.38°	Packing parameters of polymer chains	
ε_y	58.38°	μ_1	141.093
ε_z	-118.86°	w_1	-0.35
Scale factor	0.181	μ_2	145.87
Attenuation factor	18.643	w_2	0.8027

μ_1 and μ_2 are the azimuth angles, w_1 and w_2 the heights of the origin atoms

The azimuthal angles μ_1 and μ_2 are searched within the asymmetric unit by calculating R-values for the equatorial reflections (Okuyama *et al.,* 1997). The two independent polymer chains are in the same directions then we have searched the positional parameter *w* of the polymer chain along the *c*-direction. Then, this model was refined against all reflections, including unobserved ones. The weight of the reflection (w) was fixed to 1.0 for observed reflections. R and R_w were used to evaluate the agreement between observed and calculated structure amplitudes. We have carried out refinement of molecular and crystal structure parameters to minimize the difference in structure amplitudes of experimental F_{obs} and simulated F_{cal} in terms of R and R_w factors given as:

$$R = \Sigma||F_o|-|F_c||/\Sigma|F_o| ,$$

$$R_w = \Sigma\, w\,(|F_o|-|F_c|)^2/\Sigma w\, F^2_o \quad (5)$$

Final values of refined parameters are listed in Table 2. The x-ray agreement factors R and R_w are 17.43% 21.06% respectively, for reflection data. The packing structure is shown in Figure 4.

Calculation of Stiffness Constants

Modulus of elasticity of MCU-5 cotton fiber depends mainly on molecular structure and morphology (Ravve, 2000).

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & - & C_{15} & - \\ C_{21} & C_{22} & C_{23} & - & C_{25} & - \\ C_{31} & C_{32} & C_{33} & - & C_{35} & - \\ - & - & - & C_{44} & - & C_{46} \\ C_{51} & C_{52} & C_{53} & - & C_{55} & - \\ - & - & - & C_{64} & - & C_{66} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & - & S_{15} & - \\ S_{21} & S_{22} & S_{23} & - & S_{25} & - \\ S_{31} & S_{32} & S_{33} & - & S_{35} & - \\ - & - & - & S_{44} & - & S_{46} \\ S_{51} & S_{52} & S_{53} & - & S_{55} & - \\ - & - & - & S_{64} & - & S_{66} \end{bmatrix}^{-1}$$

where C_{11}, C_{22}, C_{33} are stiffness constants. C_{44}, C_{55} and C_{66} are the shear constants. C_{12}, C_{23} and C_{13} are Poisson's ratios. For simplifying the calculation, Treloar assumed the additional constants in monoclinic matrix to be equivalent the orthorhombic matrix (Treloar, 1960). The most important elastic constant is C_{22}, which gives the elastic constant along chain direction (Treloar, 1960; Jaswon, 1968), is influenced by three forces: Primary bonds (covalent bonds), inter-chain bonds (hydrogen bonds which exist between chains) and intra-chain bonds (hydrogen bonds which exist between two atoms within a chain). The C_{22} can be expressed as follows:

$$C_{22} = C^{`}_{22} + C^{``}_{22} + C^{```}_{22} \quad (6)$$

According to Treloar's (1960), $C^{`}_{22}$ is given by:

$$C^{`}_{22} = CL^2/V \quad (7)$$

Here L is repeat distance in chain direction axis, V is the volume of unit cell of cellulose (monoclinic) and C is a gross constant, which can be computed by using bond angles, bond lengths, linear force constants and angular force constants of primary bonds. $C``_2$ is computed (Treloar,1960) using:

$$C_{22}^{``} = \left(2D_2^2 / V\right)\left[C_{h2} \sin^2 \Phi_2 + \left(K_{h2} / h_2^2\right)\cos^2 \Phi_2\right] \qquad (8)$$

where Φ_2 is the angle formed by (O5 –H…O3) in the chain. Treloar (1960) has shown that:

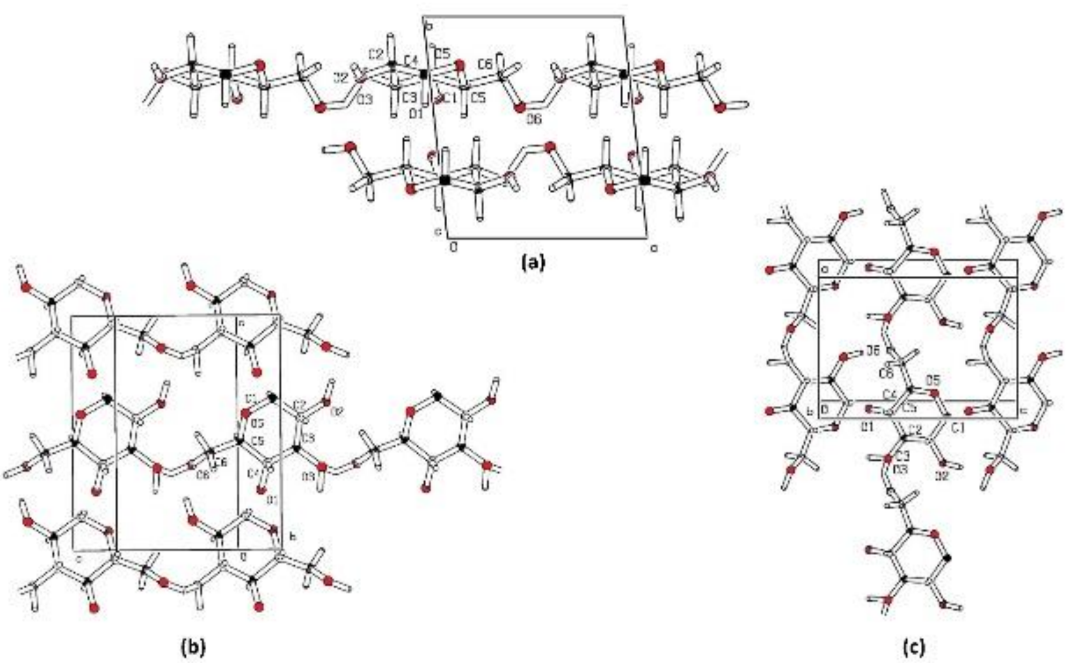
$$C_{22}^{``} = \left(2D_2^2 / V\right)\left[C_{h2} \sin^2 \Phi_2 + \left(K_{h2} / h_2^2\right)\cos^2 \Phi_2\right] \qquad (9)$$

$$C_{22}^{```} = \left(2/V\right)\left(C_{h1}h_1^2 \sin^4 \Phi_1 + C_{h3}h_3^2 \sin^4 \Phi_3 + K_{h1} \sin^2 \Phi_1 \cos^2 \Phi_1 + K_{h3} \sin^2 \Phi_3 \cos^2 \Phi_3\right) \qquad (10)$$

$$C_{33} = \left(2D_3^2 / V\right)\left[C_{h3} \cos^2 \Phi_3 + \left(K_{h3} / h_3^2\right)\sin^2 \Phi_3\right]\cos^2 \Omega_3 \qquad (11)$$

$$C_{12} = \left(2D_1 h_1 / V\right)\left[C_{h1} - \left(K_{h1} / h_1^2\right)\right]\sin^2 \Phi_1 \cos\ \Phi_1 \cos\ \Omega_1 \qquad (12)$$

$$C_{23} = \left(2D_3 h_3 / V\right)\left[C_{h3} - \left(K_{h3} / h_3^2\right)\right]\sin^2 \Phi_3 \cos\ \Phi_3 \cos\ \Omega_3 \qquad (13)$$



For explanations of angles and various symbols we refer to the reference by Treloar (1960). Utilizing all these equations, we have written a source code in FORTRAN language to calculate the elastic constants for MCU-5 cotton fibers.

Results and Discussion:

1. Molecular Structure

The molecular structure for cellulose is a typical structure with β(1–4) linked polysaccharides as observed in chitosan and chitin (Okuyama *et al.,* 1997). The main-chain conformation angles, ϕ(C2-C1-O1-C4) and ψ(C1-O1-C4-C3), are 62.80° and -66.52° respectively. The value of χ (O5-C5-C6-O6) which defines the orientation of O6, is 141.01°. This orientation of O6 is *gauche-trans* (*gt*) and this conformation being the second most common conformation in the single crystal structures of oligsaccharides and also in polysaccharides including cellulose (Allen *et al.,* 1979). Table 2 shows the final parameters of cellulose-I using LALS program obtained after several refinements. The Eulerian angles (ε_x, ε_y, ε_z) were also given in Table 2.

2. The Crystal Structure

The unit cell parameters of cotton fiber studied here are a = 7.350 Å, b = 8.220 Å, c = 10.370 Å and γ = 96.28^o with monoclinic and space group $P2_1$. The two pyrasone rings along the b-axis represent the repeating monomer of this polymer chain and the two adjacent polymer chains along b-axis are independent. These are arranged in parallel fashion. These two polymer chains have translational difference along the b-axis of approximately one fiber repeat unit and are linked to each other by inter-chain bonds (O6-H....O3) and intra-chain bonds (O3-H.....O5) along the c- and b-axes respectively (Langan *et al.,* 1999). These features make the sheet structure parallel to ac-plane. The sheets are accumulated along the c-direction, such that each neighboring sheets are related by crystallographic 2_1-symmetry.

3. Evaluation of Crystal Modulus

To calculate elastic stiffness matrix $|C_{ij}|$ we have used the values by Treloar for force constants (linear and angular) for primary bonds and hydrogen bonds

We have used bond angles and bond lengths for both primary bonds and hydrogen bonds and also auxiliary angles to calculate the elastic constants. We have adopted Treloar assumptions even though that the chains of cellulose take parallel position to each other, which is contrary to Treloar assumption. Further, hydrogen bonds of the type O-H….O are dominant within a sheet and it takes perpendicular projection with the chain axes, whereas hydrogen bonds of the type C-H….O connect between every chains in deferent sheets. Treloar has mentioned that only O-H….O type are available for calculations and this may have affect on the assumed values.

The stiffness matrix of MCU-5 cotton fibers so computed is:

$$\begin{bmatrix} 4.0\times10^{10} & -1.7\times10^{10} & - & - & - & - \\ - & 3.6\times10^{11} & -3.4\times10^{10} & - & - & - \\ - & - & 7.6\times10^{10} & - & - & - \\ - & - & - & 5.6\times10^{10} & - & - \\ - & - & - & - & 2.17\times10^{10} & - \\ - & - & - & - & - & 2.6\times10^{10} \end{bmatrix}$$

We find from above results that E_{22} value is 35.8 GPa which is higher than that reported in our paper for (dch32) cotton fiber which is (1.55 GPa), which has been calculated using intrinsic strain tensor components (Samir and Somashekar, 2007). The negative values of some Poisson's ratio in some directions denote that while stretching a chain there is a transverse expansion with stretching instead of a contraction and this is relative to longitudinal extension. This has been observed for some materials (auxetic materials such as foams cellular solid) and materials with chiral microstructure with non-central force interaction or non-affine deformation (Lakes, 1987). We have examined and quantified the disorder present in the cotton fibers using Line Profile Analysis using a well-established the single order method. The observed broadening of reflection in cotton fiber is due to crystallite size of the order 40-50 Å and intrinsic strain present in the cotton fibers. These intrinsic strain tensor components affect slightly on hydrogen bonds only and not the primary bonds. By using this assumption and neglecting the deformation of primary bonds (eq. 3), we have also recalculated the elastic constants, and we find the value of E_{22} (Young's modulus) is in agreement with the reported range of values of Young's modulus (5.5-12.5GPa) (Eichhorn *et al.,* 2001). The shear modulus has a high value in the [100] and [010] directions and are of same magnitude. The Poisson's ratios agree with the previous reported value (Robert *et al.,* 1994), which is 0.30 for microcrystalline cellulose.

Conclusion:

In this paper, first, we have recorded Wide Angle X-ray Scattering data from Dharwar cotton fiber. This WAXS data has been used to obtain the unit cell parameters and microstructural parameters of these fibers. For this purpose, we have analyzed the data using Line Profile Analysis, developed by us. The results show that the intrinsic strains components of cotton fiber are very small and have different values in different Bragg's planes. This indicates the anisotropy nature of intrinsic strains present during fiber formation. We have also constructed a molecular and crystal structure of this cotton fiber by using LALS and PLATON programs. This is based on a model wherein two chains in a unit cell are parallel with the same conformations. We have also computed the elastic constants from microstructure data. There is an agreement between our result of longitudinal Young's modulus (3.88×10^{10} N/m^2) and that of Jaswon *et al.*'s (1968) value). In the absence of primary bonds, the recalculated elastic constants give a significant value of Young's modulus (3.88×10^{10} N/m^2).

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INNOVATIVE RESEARCH TRENDS IN SCIENCE AND TECHNOLOGY: EXPLORING NEW FRONTIERS

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Introduction:

In today's rapidly evolving world, science and technology are at the forefront of addressing global challenges, improving lives, and shaping the future of humanity. From artificial intelligence (AI) to sustainable energy solutions, innovative research trends are continuously redefining the boundaries of what is possible. Below, we explore some of the most exciting and impactful research trends that are driving the future of science and technology.

Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning (ML) have moved from theoretical concepts to integral parts of industries ranging from healthcare to transportation. The current trend in AI research focuses on improving algorithms for deep learning, natural language processing (NLP), and computer vision, making systems more autonomous and human-like in their interactions (Goodfellow *et al.,* 2016). One significant area of innovation is 'explainable AI (XAI)', which seeks to make AI decisions transparent and understandable to users, addressing concerns about bias and fairness (Gilpin *et al.,* 2018). Researchers are also working on enhancing 'Reinforcement Learning' to allow machines to learn more efficiently by interacting with their environment, leading to advanced robotics and automated decision-making systems (Silver *et al.,* 2016).

Quantum Computing

Quantum computing is one of the most groundbreaking fields of research today, with the potential to solve problems that classical computers cannot address in a reasonable time. By leveraging the principles of quantum mechanics, such as superposition and entanglement, quantum computers can handle vast amounts of data and perform complex calculations at unprecedented speeds (Nielsen & Chuang, 2010).

Current research in quantum computing is focused on 'Quantum Error Correction', a key challenge in developing practical quantum computers (Raussendorf *et al.,* 2007). Additionally, 'Quantum Cryptography' and 'Quantum Networking' are on the rise, with potential applications in secure communication and information transfer that would be impervious to traditional hacking methods (Shor, 1994).

Biotechnology and Genetic Engineering

Advancements in biotechnology and genetic engineering are transforming medicine, agriculture, and environmental science. One of the most influential breakthroughs in this area has been 'CRISPR-Cas9' gene-editing technology, which allows for precise modifications of DNA, offering potential cures for genetic disorders and improved crop yields (Doudna & Charpentier, 2014).

In addition to gene editing, research in 'Synthetic Biology' expanding, aiming to design and build new biological parts, devices, and systems that do not exist in nature (Church *et al.,* 2014). Researchers are also investigating 'Bioprinting', which uses 3D printing technology to create tissues and organs, potentially revolutionizing transplant medicine (Murphy & Atala, 2014).

Renewable Energy and Sustainability

As the world grapples with the climate crisis, research into renewable energy sources has never been more critical. Innovative approaches in 'Solar Energy' such as 'Perovskite Solar Cells', are being explored to increase energy efficiency and reduce the cost of production (Kojima *et al.,* 2009). Similarly, 'Wind Energy' research is looking into offshore wind farms and high-altitude wind turbines to harness more power from natural forces (Lepore *et al.,* 2020).

Sustainability in technology is also gaining ground, with the rise of 'Circular Economy' models where waste materials are reused and recycled to minimize environmental impact (Ellen MacArthur Foundation, 2017). 'Carbon Capture and Storage (CCS)' technologies are advancing to mitigate the effects of greenhouse gases, while 'Green Hydrogen' is being researched as an alternative fuel source for industries and transport (Luo *et al.,* 2020).

Space Exploration and Technology

The exploration of outer space has seen significant advancements with the emergence of private space companies like SpaceX, Blue Origin, and others. Research in this area is focused on developing technologies for 'Interplanetary Travel', 'Space Habitats', and 'Mining Asteroids' for valuable resources (Zubrin, 2013). NASA's Artemis program aims to return humans to the Moon, while there are ongoing projects targeting 'Mars Colonization' (NASA, 2020).

Another exciting frontier in space technology is 'Satellite-based Communication', which promises to enhance global internet access, particularly in remote or underserved regions. Low Earth orbit (LEO) satellite constellations are revolutionizing global connectivity (Levine *et al.,* 2019).

5G and Next-Generation Connectivity

The rollout of 5G networks is a critical milestone in the evolution of telecommunications, enabling ultra-fast internet speeds, low latency, and the connection of billions of devices in the 'Internet of Things (IoT)' ecosystem. Research is already underway to prepare for '6G', the next generation of wireless communication, which is expected to bring advancements in areas like 'Smart Cities', 'Autonomous Vehicles', and 'Remote Healthcare' (Chen *et al.,* 2020).

The continued growth of IoT is creating opportunities for smart homes, wearables, and industrial applications. However, researchers are also focusing on securing IoT networks to prevent vulnerabilities from being exploited by cybercriminals (Roman *et al.,* 2013).

Nanotechnology

Nanotechnology is the manipulation of matter on an atomic or molecular scale, and it holds promise in various fields including medicine, electronics, and materials science. Researchers are focused on developing 'Nanomaterials' with unique properties, such as 'Carbon Nanotubes', which have applications in everything from electronics to energy storage (Saito *et al.,* 1998). In medicine, 'Nanomedicine' is emerging as a powerful tool for targeted drug delivery, cancer treatment, and diagnostic imaging (Nel *et al.,* 2009).

Human Augmentation and Wearable Technologies

Human augmentation refers to enhancing the human body's capabilities through technology. Research in this field includes innovations in 'Prosthetics', 'Exoskeletons', and 'Brain-Machine Interfaces (BMIs)'. These technologies can help people with disabilities regain lost functions and even enhance the physical abilities of healthy individuals (Lebedev & Nicolelis, 2006).

'Wearable Technologies', such as smart-watches and fitness trackers, are also becoming more advanced, monitoring everything from heart rate to blood glucose levels. Researchers are exploring how these devices can be used to prevent illness, monitor mental health, and improve overall wellness (Patel *et al.,* 2012).

Cybersecurity and Privacy

As technology becomes more integrated into our daily lives, the need for robust cybersecurity and privacy measures is more pressing than ever. Researchers are focused on developing 'Aadvanced Encryption Techniques', 'AI-Powered Threat Detection', and 'Blockchain technology' to safeguard personal and sensitive data (Nakamoto, 2008).

The rise of 'Quantum Computing' poses both a challenge and an opportunity for cybersecurity, as quantum algorithms could potentially break current encryption systems.

Researchers are working on 'Quantum-Safe Cryptography' to prepare for this new era of computing (Lynch *et al.,* 2016).

Ethics in Technology

As technology evolves, ethical considerations are increasingly important. Research into the 'Ethical Implications of AI', 'Privacy Concerns in Big Data', and the responsible use of biotechnology are vital for ensuring that innovation serves humanity's best interests. Policymakers and researchers are also exploring frameworks for regulating emerging technologies to ensure they are used safely and equitably (Floridi, 2016).

Conclusion:

The rapid advancements in science and technology are creating new opportunities to tackle global challenges, enhance human well-being, and explore the farthest reaches of the universe. However, these innovations also come with their own set of challenges, including ethical dilemmas, security risks, and societal implications. Continued research and collaboration across disciplines will be crucial in ensuring that these technologies are developed and implemented in a responsible and sustainable manner, ultimately shaping a better future for all.

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RECENT PHARMACEUTICAL APPLICATIONS OF 1,2,4-TRIAZOLE DERIVATIVES

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Abstract:

1,2,4-Triazole derivatives have garnered significant attention in the pharmaceutical field due to their diverse biological activities, including antimicrobial, anticancer, anti-inflammatory, and neuroprotective properties. These compounds are part of the broader class of triazoles, which are recognized for their versatile chemical structure and ability to interact with various biological targets. This review aims to provide an overview of recent advancements in the pharmaceutical applications of 1,2,4-triazole derivatives, focusing on their synthesis, biological activities and potential therapeutic roles. We discuss the impact of these compounds on disease treatments, particularly in the context of emerging therapeutic areas, such as antimicrobial, antitubercular and anticancer therapy. Finally, the review addresses the challenges and future directions in the development of 1,2,4-triazole-based drugs.

Keywords: 1,2,4-triazole, Anticancer, Antitubercular, Antimicrobial

Introduction:

Triazoles are cyclic compounds consisting of five members, including three nitrogen atoms and two carbon atoms. These molecules can engage in interactions with various proteins, enzymes, and receptors within living organisms through weak bonding. Triazole can exist in two different isomeric forms: 1,2,4-triazole and 1,2,3-triazole (Fig. 1).[1] The 1,2,4-triazole moiety alters a compound's polarity, hydrogen bonding ability, and lipophilicity, thereby enhancing its pharmacological, pharmacokinetic, toxicological, and physiochemical properties.[2-3]

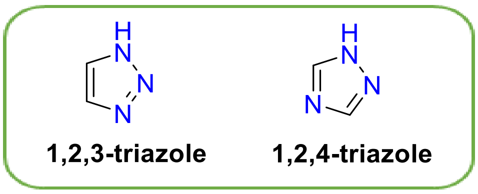


Fig. 1: Structures of isomeric forms of triazoles

A variety of pharmaceuticals containing the 1,2,4-triazole structure are available in the market (Fig. 2), including: Antifungal agents[4-7] —myclobutanil, tebuconazole, posaconazole, fluconazole; Anticancer drugs[6,8] —anastrazole, litrozole, and vorozole; Antimigraine medications[6, 9] —rizatriptan; and Antiviral treatments[6,10] —ribavirin.

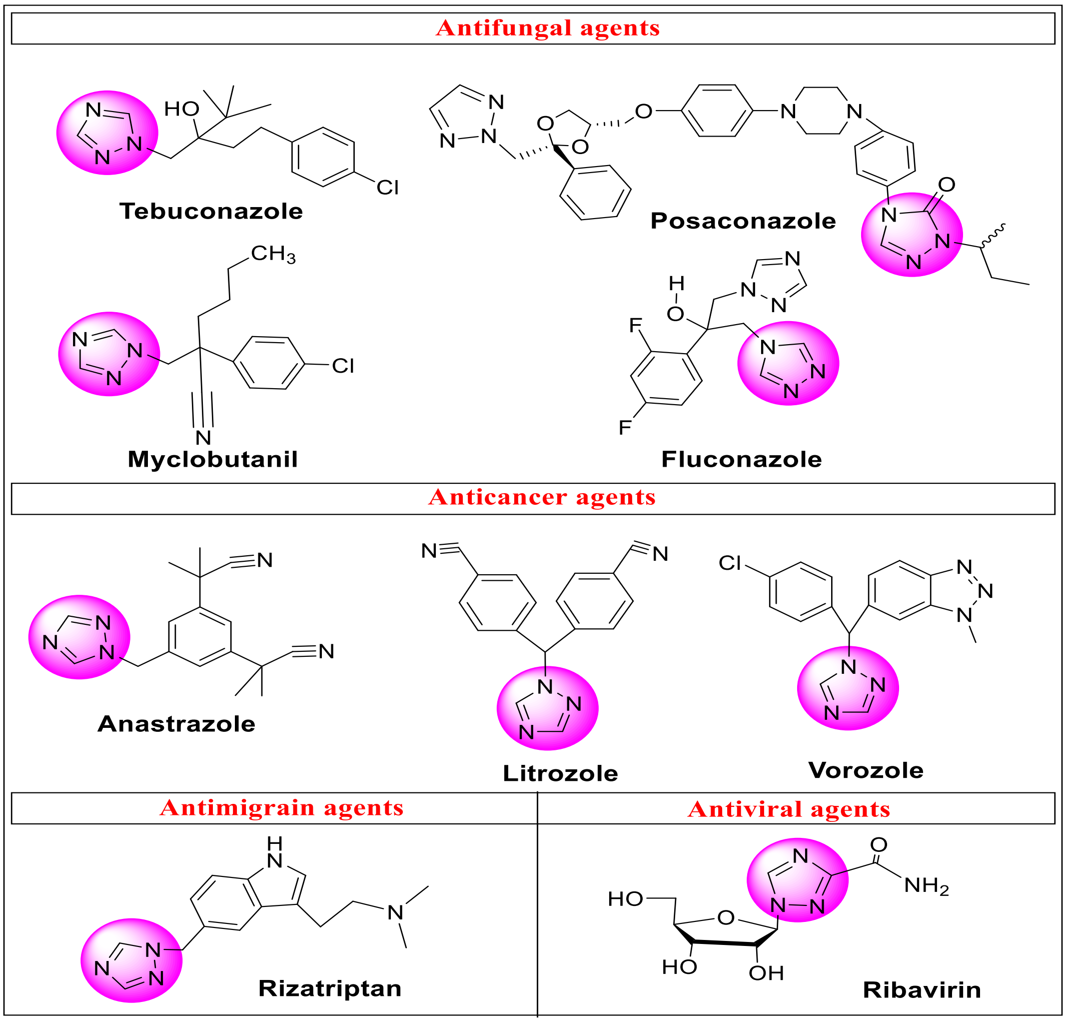


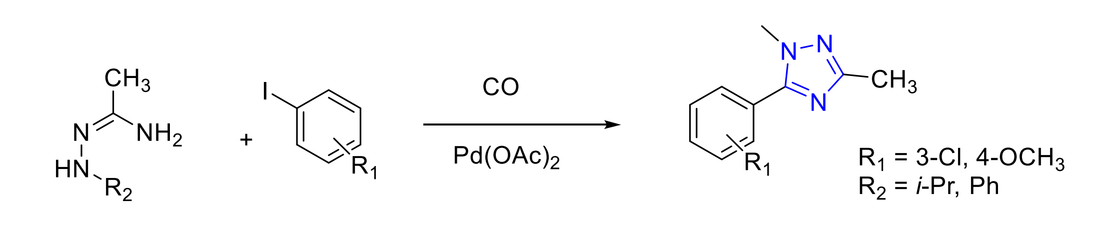
Fig. 2: Chemical formulas of various marketed medications that are based on bioactive 1,2,4-triazole compounds

The 1,2,4-triazole ring system has shown a unique ability to interact with biological macromolecules, including enzymes, receptors, and nucleic acids, making it a valuable scaffold for drug discovery. 1,2,4-Triazole derivatives are an important class of heterocyclic compounds that have been widely studied for their pharmacological potential as antimicrobial agents,[11-13] anti-tubercular agents,[14-16] anticonvulsant,[17-18], antidepressant,[19-20] hypoglycemic,[21] and immunosuppressant.[22]

The rise of multidrug-resistant pathogens and the increasing prevalence of chronic diseases have prompted an urgent need for new and more effective drugs. 1,2,4-Triazole derivatives have emerged as promising candidates to address these challenges. This review discusses the synthesis, pharmacological activities, and the current state of 1,2,4-triazole-based drug development.

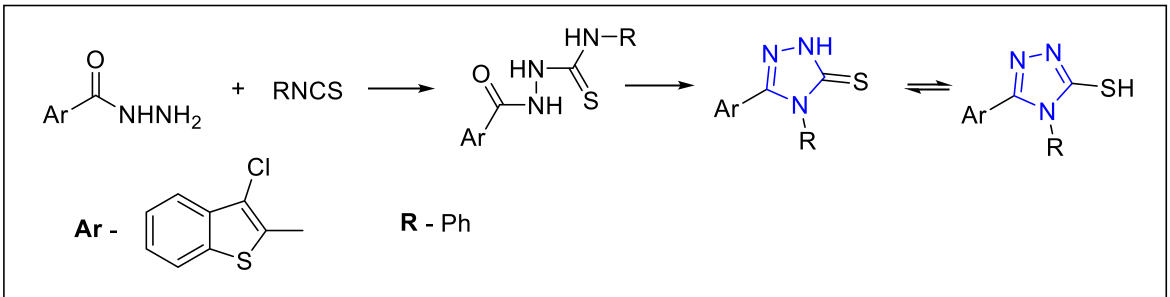
Synthesis of 1,2,4-Triazole Derivatives

The synthesis of 1,2,4-triazole derivatives can be achieved through several approaches, including cyclization reactions, condensation methods, and multicomponent reactions. One common synthetic route involves the reaction of hydrazines with α, β-unsaturated carbonyl compounds, leading to the formation of the 1,2,4-triazole ring (Scheme 1).[23]



Scheme 1: Synthesis of 1,2,4-triazole from hydrazine

Other methods include substitution reactions, where various electrophilic species, such as isocyanates or thiocyanates, react with hydrazines to yield triazole derivatives (Scheme 2).[24-26]



Scheme 2: Synthesis of 1,2,4-triazole from thiocynates

Recently, advances in green chemistry have provided more sustainable methods for the synthesis of 1,2,4-triazoles, using non-toxic solvents and energy-efficient processes.[27-29] Additionally, the development of microwave-assisted and solvent-free reactions has further streamlined the production of 1,2,4-triazole derivatives, enhancing both yield and purity.[30-31]

Functionalization of the triazole ring allows for the creation of a wide range of derivatives, each possessing unique biological activities. Substituents such as halogens, alkyl groups, and aromatic rings can be introduced to modulate the pharmacological properties of the compounds.

Pharmaceutical Applications of 1,2,4-triazole:

Antimicrobial Activity

Bitla *et al.* (2021)[32] synthesized the series of novel compounds of bis-1,2,3 and 1,2,4-triazoles and examined for their antioxidant, antifungal, and antimicrobial properties. A notable range of antibacterial activity was found in two compounds 1(a, b) (Fig. 3). Similarly, Ali *et al.* (2023)[33] prepared Schiff bases of several benzaldehyde derivatives with 3-amino-1,2,4-triazole-5-thiol in the presence of morpholin. Further, all produced compounds were screened for biological activity against four different kinds of bacteria, both Gram-positive and Gram-negative. The compound 2a (Fig. 3) exhibited the largest inhibitory impact on *Klebsiella pneumoniae*, with an IC50 of 15 µg/mL, whereas 2b (Fig. 3) inhibited *Staphylococcus aureus* with an IC50 of 22 µg/mL, according to the study.

Osmaniye *et al.* (2023)[34] prepared 17 novel triazole derivatives and assessed them on *Candida* strains using *in-vitro* technique. Compound 3 (Fig. 3) exhibited MIC90 = 2 µg/mL activity against *Candida glabrata* and *Candida krusei*. This activity rating is encouraging because it is higher than that of fluconazole.

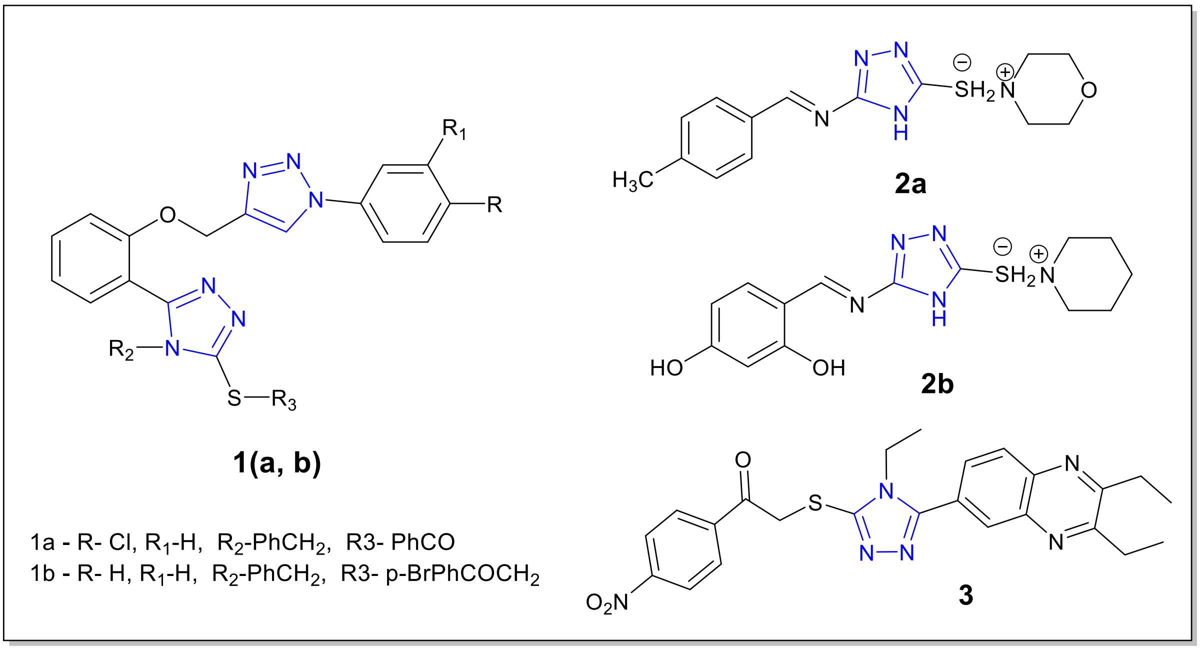


Fig. 3: 1,2,4-triazole derivatives showing Anti-microbial activity

Anticancer Activity

Tolan *et al.* (2023)[35] reported the new synthesized 1,2,4-triazole glycoside derivatives 4a, 4b, 4c and 4d (Fig. 4) and evaluated for anti-proliferative activity. The compounds were shown to possess anticancer properties *in-vitro* against several human cancer cell lines, which includes MCF-7 and HCT-116.

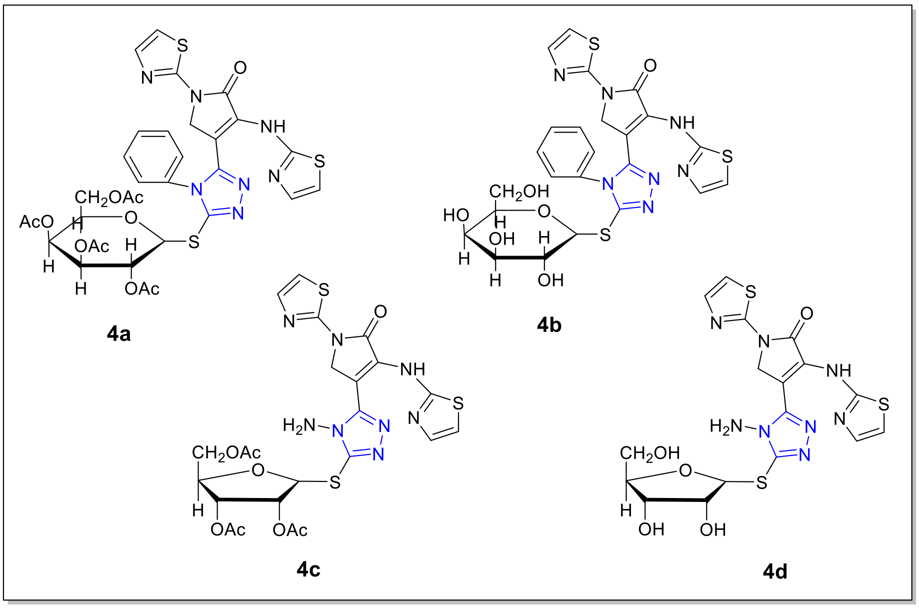


Fig. 4: 1,2,4-triazole glycoside derivatives showing Anticancer activity

Emami *et al.* (2022)[36] reported nineteen new 1,2,4-triazole derivatives, including 1,3-diphenyl-2-(1H-1,2,4-triazol-1-yl. The compounds were tested against three human cancer cell lines: MCF-7, Hela, and A549. Compounds 5a, 5b, 5c and 5d (Fig. 5) exhibited a potential cytotoxic activity lower than 12 µM against Hela cell line. Further, molecular docking studies were conducted to understand their binding modalities.

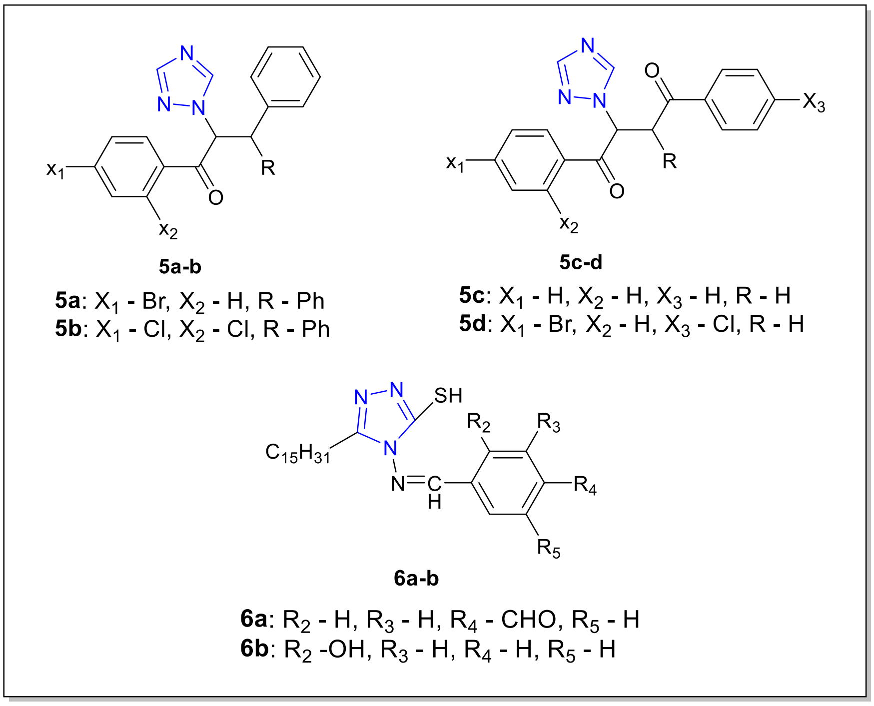


Fig. 5: 1,2,4-triazole derivatives showing Anticancer activity

Kumari *et al.* (2021)[37] prepared twenty 1,2,4-triazole derivatives using a multi-step synthesis procedure that started with palmitic acid. Additionally, 5-FU was used as a standard for the *in-vitro* anticancer evaluation against the MCF-7 and HCT116 cancer cell lines. Compounds 6a (IC50=3.84 μM) and 6b (IC50=3.25 μM) (Fig. 5) had the strongest anticancer activity against HCT116 cell lines in comparison to regular 5-FU (IC50=25.36 μM).

Antitubercular Activity

Yang *et al.* (2024)[38] prepared series of new 1,2,4-triazole containing aryl fluorosulfate compounds. Among them, compound **7** (Fig. 6) demonstrated good *in-vivo* mouse plasma exposure and lung concentration against Mtb, with an *in-vitro* minimum inhibitory concentration of 0.06 μM and no cytotoxicity against HEK293T or HepG2 cell lines.

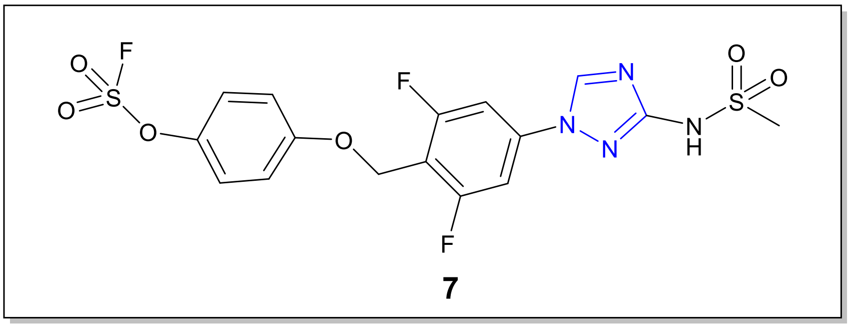


Fig. 6: 1,2,4-triazole containing aryl fluorosulfate derivatives showing Antitubercular activity

Naik *et al.* (2024)[39] reported the hybrid molecules combining 1,2,4-triazole and pyrazine scaffolds having ability to effectively combat the Mycobacterium TB H37Rv strain. Eight compounds 8a – 8h (Fig. 7) showed significant action against Mtb, with MIC of ≤21.25 μM.

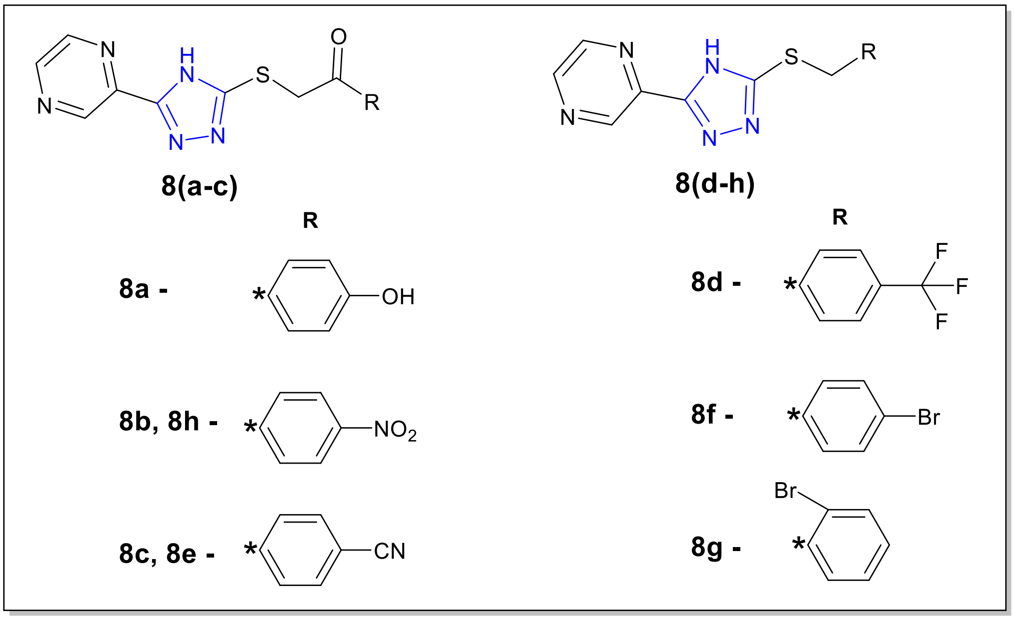


Fig. 7: 1,2,4-triazole derivatives showing Antitubercular activity

Moreover, when 1,2,4-triazole derivatives are combined with imaging agents, opportunities for diagnostic applications emerge. Compounds based on triazole are being utilized to create molecular imaging agents, which aid in the detection and monitoring of cancer, resulting in more precise diagnoses and treatment strategies.

Challenges and Future Directions

Despite the significant potential of 1,2,4-triazole derivatives in medicine, several challenges persist in their development. Key issues involve their toxicity levels, the necessity for improved bioavailability, and the intricacies associated with large-scale production. Additionally, the resistance that can develop against triazole-based medications, especially among antifungal and antibacterial agents, remains a critical issue.

Future studies should concentrate on fine-tuning 1,2,4-triazole derivatives to better their pharmacokinetic characteristics, enhance their specificity for targeted sites, and reduce unintended effects. Furthermore, exploring combination therapies where triazole derivatives are used alongside other medications or biologics may yield more effective solutions for complex diseases like cancer and chronic infections.

Conclusion:

In summary, 1,2,4-triazole derivatives are a promising category of compounds with diverse pharmaceutical applications. Their properties, including antimicrobial, anticancer and anti-tubercular position them as valuable candidates for drug development. With continuous improvements in their synthesis, enhancement, and clinical assessments, 1,2,4-triazole derivatives are expected to play an increasingly vital role in tackling global health challenges, including drug-resistant infections, cancer, and neurodegenerative disorders.

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INTRODUCTION TO GRAPHENE, GRAPHENE OXIDE AND GRAPHENE OXIDE QUANTUM DOTES: A REVIEW

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Abstract:

Carbon, the sixth element in the periodic table, was first identified by Antoine Lavoisier in 1789. Its versatility arises from its ability to bond in various ways, forming allotropes with distinct properties. Diamond, one of the hardest known materials, and graphite, one of the softest, demonstrate this diversity. The unique properties of these allotropes stem from carbon's shared valence electrons, with graphite's layered structure and weak van der Waals forces facilitating easy separation of individual graphene sheets. The discovery of fullerenes in 1985, carbon nanotubes in 1991, and graphene in 2004 marked significant milestones in material science, particularly for their applications in electronics and nanotechnology. Graphene, with its honeycomb lattice structure, exhibits extraordinary conductivity, mechanical strength, and thermal properties, making it ideal for a wide range of applications in optoelectronics and energy storage. However, the high cost and low yield of graphene have led researchers to explore graphene oxide (GO) as an alternative. GO, an oxidized form of graphene, can be synthesized cheaply and easily through methods like Hummer's process. Its properties, such as tunable conductivity, high surface area, and biocompatibility, make it valuable for applications in water purification, drug delivery, and energy storage. Furthermore, the reduction of GO to form reduced graphene oxide (rGO) restores some of its original conductivity, enhancing its functionality. In addition, the conversion of graphene into zero-dimensional graphene oxide quantum dots (GOQDs) introduces new possibilities due to their unique luminescent properties, excellent solubility, and biocompatibility, which are beneficial for bioimaging, sensing, and energy storage. This article explores the brief introduction to carbon-based materials such as Graphene, Graphene oxide, graphene oxide quantum dots and their unique properties with application highlighting their significant contributions to modern technology

Keywords: Carbon-Based Materials, Graphene Oxide, Graphene Oxide Quantum Dots

Introduction to Carbon Materials:

Carbon, the sixth element in the periodic table was discovered by A.L Lavoisier in 1789. Carbon's uniqueness lay in its ability to bond in different ways forming different carbon allotropes, with completely different properties, for example, diamond which is one of the hardest known materials on earth and graphite which is one of the softest materials. These different allotropes are due to equally shared valance electrons of carbon. Graphite is one of the naturally occurring allotropes of carbon and is mostly found in metamorphic rocks, igneous rocks and in meteorites [1]. The lattice structure of graphite contains two-dimensional lattice bond whereas diamond contains three-dimensional lattice bond. Graphite has a layered and planar structure and each layer of graphite binding through weak van der Waals force which eases the separation of a single layer of graphite. Such individual layers of graphite are known as Graphene. Each layer of graphite consists of carbon atoms that are arranged in a hexagonal lattice with separation of 0.142 nm and distance between two graphene sheet is 0.335nm [2]. Of the four potential sites, the carbon atoms in graphite covalently bonded with three of these and the fourth electron is free to move in the plane, thereby making the graphite electrically conductive. In graphite, carbon has the lowest energy state at ambient temperature and pressure. Study about the carbon nanomaterials became important with the discovery of fullerenes in 1985 [3], carbon nanotubes in 1991[4] and the wonder material, graphene in 2004 [5]. Fullerene (C_{60}) was discovered by Richard Smalley and his co-workersin 1985 at Rice University. Fullerenes are an allotrope of carbon and may exist in forms such as a hollow sphere (Buckyballs), ellipsoid, tube etc. The cylindrical form of fullerenes is also known as Carbon nanotubes (CNTs)(Buckytubes). Multi-wall CNTs were first reported in 1991 by Sumio Lijima and just after a couple of years from the discovery of multi-walled CNTs; he was also able to observe single wall CNTs. The discovery of bucky balls and buckytubes accelerated the research in materials science and their technology application especially in electronics and nanotechnology [6].

Graphene:

Graphene is one of the most exciting 2D materials in the 21st century which has a single atom thick layer of carbon arranged in a hexagonal honeycomb lattice as shown in fig. 1 (d) and has high crystal quality. In 2004, a new era in the field of material science and condensed matter physics was an opened when Andre geim and Konstantin Novoselov of the University of Manchester succeeded in obtaining a single layer of graphene from graphite source through the so called “Scotch tape” technique. In this approach single layer or few layered graphene sheets can be obtained by repeated peeling of highly oriented pyrolytic graphite (HOPG) using scotch tapes. Even at present, the simple but efficient “scotch tape” technique is still a common process in order to obtain high-quality graphene. The two were awarded the Nobel Prize in Physics in 2010 for their achievement and for opening new doors to research in the field of two-dimensional materials. Since the discovery of graphene in 2004, it has gained a lot of attention amongst the researchers sue to its remarkable properties such as high mechanical stiffness, high transparency, extremely light, and outstanding electrical and thermal conductivity which are not generally present in a single bulk material. The experimentally measured thermal conductivity for micrometer-sized 2D graphene sheet lies in the range of 2500–5000 W/m K [7]. The mobility of graphene is theoretically limited to $\mu = 20000$ cm^{-2} V^{-1} S^{-1} by acoustic phonons at a carrier density of n= 10^{12} cm^{-2}. The flat hexagonal lattice of graphene offers relatively little resistance to electrons carrying electricity which is even better than the commonly used conductors such as copper. Also, at room temperature graphene has a theoretical resistivity limit of 10^{-6}ohm-cm which makes it one of the materials with lowest resistivity [8]. Owing to such extraordinary optical and electrical properties, graphene has become a potential candidate for optoelectronic applications.

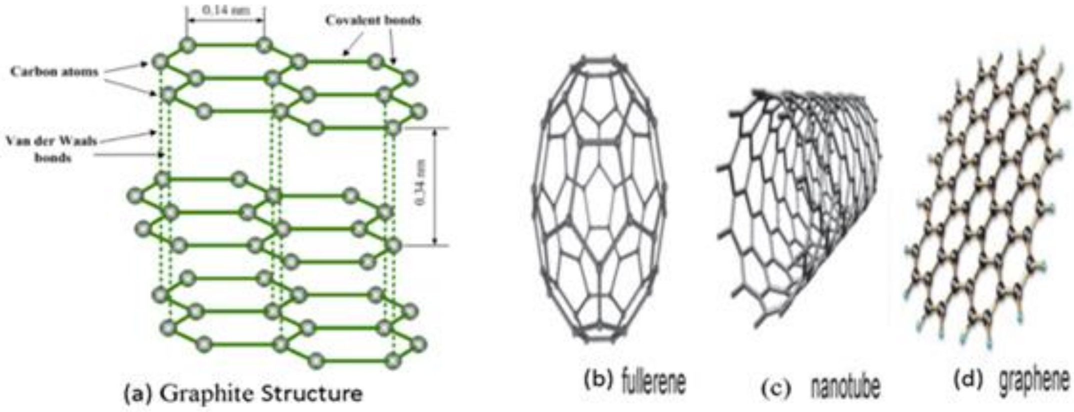

Fig. 1: Crystal Structure (a) Graphite (b) Fullerene (C60), (c) Carbon nanotubes and (d) Graphene [22]

Graphene Oxide (GOs)

Due to the high production cost and low yield of graphene, researchers have been focusing more on the oxidized form of graphene which is also known as graphene oxide (GOs). It is a derivative of graphene which can be easily prepared in bulk by simple oxidation of graphite with strong oxidizing agents. The low cost of graphite precursor and the oxidizing agents make the overall synthesis of GOs very cost effective. Graphite or graphene oxide was first reported by British chemist Benjamin C. Brodie in 1859. One of the reactions performed by C. Brodie involved the treatment of graphite with potassium chlorate and nitric acid which resulted in a yellowish product named as graphitic acid [9]. In 1898, Staudenmaier came up with a small modification in Brodie's method in which along with the precursors used by Brodie, an additional amount of sulfuric acid (H_2SO_4) was introduced in the mixture in order to increase the overall acidity and the extent of oxidation [10]. After Staudenier, Hummer and Offeman in 1958 came up with a safer, quicker and more efficient method to synthesize GOs which is still used by researchers today and is widely known as the "Hummer's method". This method involves a mixture of graphite powder, sulfuric acid(H_2SO_4), sodium nitrate ($NaNO_3$) and potassium permanganate ($KMnO_4$). The properties of graphene oxide vary depending on the degree of oxidation and the synthesis method followed [11, 12]. In the recent years, few modifications to the Hummer's method have been reported [13, 14] to synthesize high-quality graphene oxide. The graphene oxide synthesized through the Hummer's method consists of several layers of staked graphene with oxygen-containing groups such as hydroxyl, epoxy, carbonyls, carboxylic acid etc. When the graphene oxide is exfoliated, it yields a 2-dimensional single layer of carbon atoms with the oxygen functional groups attached to its basal plane and edges. The interlayer spacing between the graphene oxide layer is two times larger (~0.7 nm) than that of the graphite layer and the thickness of the graphene oxide layer are about 1.1 nm.[15] Graphene oxide has its own scientific importance as a unique form of oxidized carbon.

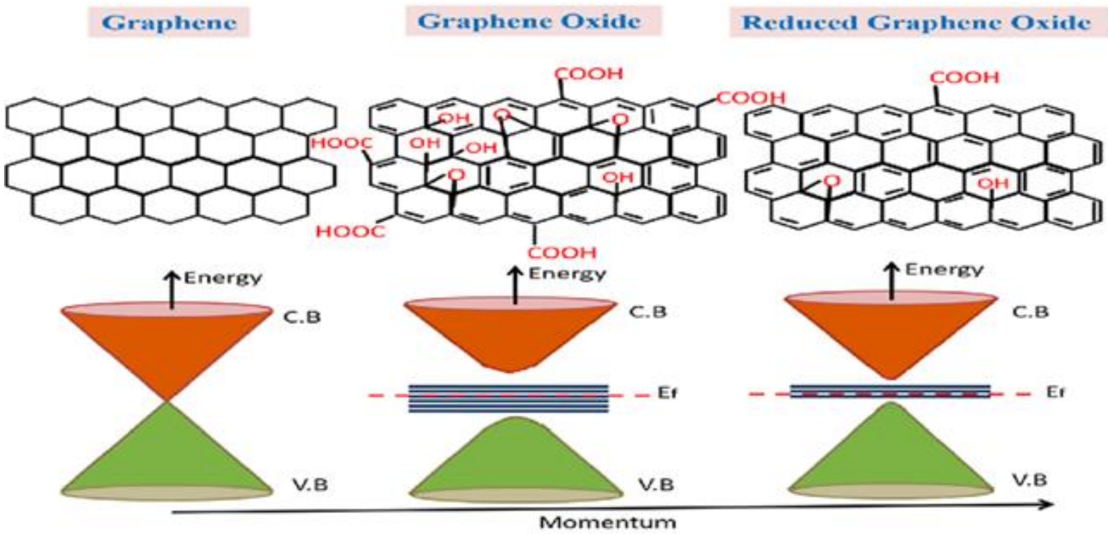

Fig. 2: Lattice structure and Band diagram of Graphene, Graphene Oxide and reduced graphene oxide [32]

The oxygen functionalized basal plane of graphene oxide allows it to form a stable suspension in most of the solvent like water, Methanol, Acetone, Ethanol, DMF, DMA, DMSO, etc. [16]. Also, it is well known that graphene is a good conductor of electricity whereas pristine graphene oxide is an insulator. The conductivity of graphene oxide depends on the degree of oxidation. During the oxidation, sp^2 bonded carbons are being replaced by the distorted sp^3 bonded ones. This replacement of sp^2 carbons results in the opening of a band gap. When all the sp^2 carbons are replaced through complete oxidation of GOs, it results in further separation of the energy bands thereby making GOs behave as an insulator. The electrical conductivity of GOs can be restored by removing some of the oxygen functionalities through various reduction techniques such as thermal reduction, microwave irradiation, chemical reduction etc. The product thus obtained is known as reduced graphene oxide (rGOs). The removal of oxygen functionalities results in decrease in the amount of distortion and restores the sp^2 bonded domain in its structure. Both GOs and rGOs have significant applications in optoelectronics, energy storage, sensing application etc. [17]. The lattice structure and the energy band diagram of graphene, graphene oxide, reduced graphene oxide is shown in the fig.2

Graphene Oxide Quantum Dots (GOQDs)

Quantum dots (QDs) are zero-dimensional material with a size in the range of few nanometers. The size dependent tunable properties of quantum dots have a lot of applications in the field of optoelectronics such as a transistor, solar cells, LEDs, diode laser, quantum computing and medical imaging [18]. However, compared to other QDs, carbon dots are superior in terms of their chemical inertness and excellent biocompatibility [19]. Also, graphene quantum dots (GQDs) and GOQDS, as a kind of carbon dots, may have the promising performance which can be comparable to that of graphene. In order to further extend the application of graphene in nanotechnology, one of the most promising routes is the conversion of 2D graphene sheet into zero dimensional GQDs or GOQDs. Due to their quantum confinement, these QDs exhibit properties some of which differ from those exhibited by graphene or GOs. For example, the GQDs or GOQDs possess luminescent properties [20] which is absent in their 2D counterpart. The graphene/GOs based quantum dots can be synthesized through various methods such as hydrothermal, chemical cutting, microwave irradiation method etc. of which the chemical synthesis is the most widely used method. The chemical approach of QDs synthesis can be further sub-divided into the bottom-up [21] and top-down approach [22]. The luminescent properties possessed by GQDs/GOQDs are size dependent and it has been experimentally found that the luminescence vary along the entire visible region. Such remarkable properties along with tunable character provide a lot of applications for the GQDs/GOQDs in the fields of bio-sensing, drug delivery etc.

Unique Properties of Graphene, GOs, GOQDs:

1. Graphene

Graphene, a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice, exhibits a remarkable set of properties that set it apart from other materials. One of its most striking characteristics is its extraordinary electrical conductivity. Graphene's electrons move at near-light speeds due to the material's unique electronic structure, making it an excellent conductor of electricity [25] Additionally, graphene has high thermal conductivity, allowing it to efficiently transfer heat, which is advantageous in a wide range of applications, including electronics and energy storage [23]

Mechanical properties of graphene are equally impressive. It is one of the strongest materials known, with a tensile strength over 100 times greater than steel [26]. Despite its strength, graphene is also remarkably flexible, maintaining its integrity even when stretched, which opens up possibilities for flexible electronic devices and materials. Furthermore, graphene is extremely lightweight, making it ideal for use in composites and lightweight structural materials [5].

Graphene also exhibits unique optical properties, including a high level of transparency and the ability to absorb a significant amount of light, which is useful in photodetectors, solar cells, and touchscreens [24].

2. Graphene Oxide (GOs)

Graphene oxide (GO), a derivative of graphene, is composed of a single layer of carbon atoms with various oxygen-containing functional groups, including hydroxyl, epoxy, and carboxyl groups. These functional groups impart unique properties to GO, making it highly versatile for a wide range of applications. One of the most significant properties of GO is its hydrophilicity, which results from the presence of oxygen groups on its surface. This allows GO to disperse easily in water and other solvents, enhancing its suitability for biological and environmental applications [29].

GO also exhibits excellent tunability of its electrical properties. While graphene is a conductor, GO is an insulator due to the disruption of its sp^2 bonding network by oxygen groups, which can be reduced back to graphene-like materials with controlled conductivity. Additionally, GO's high surface area, coupled with the presence of functional groups, enables it to act as an effective adsorbent for various molecules, including heavy metals and organic pollutants, making it useful in water purification and environmental remediation.
The biocompatibility of GO is another significant property, which allows its use in biomedical applications such as drug delivery, bioimaging, and tissue engineering [30]

3. Graphene Oxide Quantum Dots (GOQDs)

Graphene oxide quantum dots (GOQDs) are a fascinating subclass of carbon-based nanomaterials, derived from graphene oxide, that exhibit unique properties due to their nanoscale size and high surface-to-volume ratio. One of the most remarkable properties of GOQDs is their strong fluorescence, which can be tuned by adjusting their size, surface functionalization, and preparation methods [28] This fluorescence makes GOQDs ideal for applications in bioimaging, sensing, and optoelectronics. Additionally, GOQDs possess excellent water solubility, attributed to the oxygenated functional groups (hydroxyl, carboxyl, and epoxy groups) on their surface, which also contribute to their high dispersibility in aqueous solutions [31].

Another unique characteristic of GOQDs is their biocompatibility and low toxicity, which make them suitable for biomedical applications, such as drug delivery and photodynamic therapy [30] Their ability to efficiently interact with biomolecules and target specific cells or tissues enhances their potential in personalized medicine. Moreover, GOQDs exhibit significant electrochemical properties, including high conductivity, making them attractive for use in sensors, energy storage devices, and catalysis [29]. The tunability of these properties, along with their scalability, positions GOQDs as promising candidates for various emerging technologies.

Summary:

Carbon, discovered by A.L. Lavoisier in 1789, is unique for its ability to bond in various ways, forming different allotropes like diamond and graphite, which exhibit drastically different properties. Diamond is one of the hardest materials on Earth, while graphite is one of the softest. These variations arise from the arrangement of carbon's valence electrons. Graphite's layered structure, bound by weak van der Waals forces, allows its layers (graphene) to be separated easily. Graphene, a single layer of carbon in a hexagonal lattice, was isolated in 2004 by Andre Geim and Konstantin Novoselov, earning them the Nobel Prize in 2010. It boasts exceptional electrical, thermal, and mechanical properties, such as high conductivity and flexibility.

Graphene oxide (GO) is an oxidized form of graphene that is cost-effective and easier to produce. It can be synthesized using methods like Hummer's, which involve strong oxidizing agents to attach oxygen functional groups to graphene, making it more soluble and less conductive. Reduced graphene oxide (rGO) restores graphene's conductivity by removing some oxygen groups. Both GO and rGO have applications in electronics, energy storage, and biosensing.

Graphene oxide quantum dots (GOQDs) are small, luminescent particles derived from GO. They exhibit size-dependent properties such as fluorescence, making them useful in bioimaging, drug delivery, and optoelectronics. GOQDs are highly biocompatible, chemically inert, and have excellent electrochemical properties, making them ideal for various emerging technologies in sensing, energy storage, and catalysis.

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FRW COSMOLOGICAL MODELS WITH BULK VISCOSITY AND POLYTROPIC EQUATION OF STATE PARAMETER

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Abstract:

This chapter explores the viscous FRW model with a polytropic equation of state, Bulk Viscosity, and varying deceleration parameters. Exact solutions in the FRW metric are derived from the general theory of relativity, including the effects of bulk viscosity. A variable deceleration parameter results in an accelerating universe. The model's physical, geometrical, and stability properties are analyzed using the energy-momentum tensor. Exact solutions are obtained with a polytropic equation of state and variable Bulk Viscosity, and the kinematical and geometrical parameters are derived.

Keywords: Polytropic Equation of State, FRW Model, Bulk Viscosity

Introduction:

Due to its potential to resolve unresolved cosmological questions, including the late-time accelerated expansion of the universe and entropy formation in the early cosmos, the study of cosmological models integrating bulk viscosity has attracted considerable attention recently. Bulk viscosity modifies the standard energy-momentum tensor, allowing for a more realistic description of cosmic fluid dynamics, and has been applied within various modified theories of gravity and alternative cosmological frameworks.

Recent research explores the implications of bulk viscosity in different cosmological scenarios. Munyeshyaka *et al.* (2024) investigated perturbations in a modified Chaplygin gas cosmology, showing how bulk viscosity influences the evolution of perturbations in a non-ideal fluid framework. Similarly, Koussour *et al.* (2024) analyzed observational constraints on viscous fluid models in f(R, T) gravity, demonstrating the compatibility of bulk viscous cosmologies with current observations. These investigations shed important light on how viscosity influences the kinematics and dynamics of the universe.

Solanki *et al.* (2024) investigated bulk viscous cosmological models in f(T, T) gravity, shedding light on the influence of viscosity on late-time cosmic behavior in the context of modified gravity theories. Rana and Sahoo (2024) further extended this analysis by studying bulk viscosity in symmetric teleparallel gravity, placing constraints on model parameters using cosmological data.

Earlier work by Koussour *et al.* (2022) focused on extended symmetric teleparallel gravity, where they explored the effects of a bulk viscous fluid on the universe's evolution. Dwivedi's (2022) paper investigates the dynamics of Friedmann-Robertson-Walker (FRW) cosmological models under the assumption of a constant ratio between matter-energy density and vacuum energy density. This specific scenario is significant because it allows for an analytical exploration of how these components evolve in a homogenous and isotropic universe. Furthermore, Mazumdar *et al.* (2024) offered a framework for cosmic bounce situations by proposing a fresh parametrization for bulk viscosity. These results demonstrate how bulk viscosity can be used to address early- and late-time phenomena in the history of the universe.

These investigations provide fresh insights into the dynamics of the cosmos by including bulk viscosity in cosmological models and advancing our knowledge of the interaction between matter, energy, and geometry.

In this chapter, we examined cosmological models using the polytropic equation of state and bulk viscosity.

Metric and Field Equations

We consider homogeneous and isotropic spatially flat Robertson-Walker line element of the form

$$ds^2 = -dt^2 + R^2(t)[dx^2 + dy^2 + dz^2] \quad (1)$$

where $R(t)$ is the scale factor.

The energy-momentum tensor for bulk viscous fluid is taken as

$$T_{ij} = (\bar{p} + \rho)u_i u_j + \bar{p} g_{ij} \quad (2)$$

where ρ is proper energy density and $\bar{p}$ is the effective pressure given by

$$\bar{p} = p - \xi u^i_{;i} \quad (3)$$

satisfying equation of state.

In the above equation p is the isotropic pressure and u_i is the four-velocity vector satisfying $u^j u_j = 1$,The Einstein field equations (in gravitational units $8 \pi G = c = 1$) and varying cosmological constant $\Lambda(t)$, in comoving system of coordinates reduces to

$$\bar{p} - \Lambda = (2q - 1)H^2 \quad (4)$$

$$\rho + \Lambda = 3H^2 \quad (5)$$

In the above equation, H is the Hubble parameter and q is the deceleration parameter defined as

$$H = \frac{\dot{R}}{R} \quad (6)$$

$$q = -\frac{R\ddot{R}}{\dot{R}^2} \quad (7)$$

where an overhead dot (.) represents ordinary derivative with respect to t. The vanishing divergence of Einstein tensor gives rise to

$$\dot{\rho} + 3(\rho + \bar{p})H + \dot{\Lambda} = 0 \quad (8)$$

Solutions of field equations

The equations (4) and (5) are two equations involving five unknown variables R, ρ, Λ, p and ξ so in order to close the system, we need three extra condition.

We consider the extended symmetric bouncing cosmology characterized by scale factor [Bamba *et al.* (2014)] as

$$R(t) = Je^{\frac{\eta t^2}{t_*^2}} \quad (9)$$

where t_* and t are an arbitrary and cosmic time, η & J are positive constants.

From eq. (7) and (9), we get

$$q = -1 - \frac{t_*^2}{2\eta t^2} \quad (10)$$

Spatial volume, Hubble's parameter, and Scalar expansion are given by

$$V = \left[Je^{\frac{\eta t^2}{t_*^2}}\right]^3, \; H = \frac{2\eta t}{t_*^2}, \; \Theta = \frac{6\eta t}{t_*^2} \quad (11)$$

We consider Polytropic equation of state [Sarkar (2016), Kleidis and Spyrou (2015), Rahman and Ansari (2014), Malekjani (2013)] as

$$p = \alpha\rho^l - \rho \quad (12)$$

where α and l are polytropic constant and index, respectively.

Also, we choose the coefficient of bulk viscosity,

$$\xi = \frac{1}{\xi_0 + R(t)} \quad (13)$$

where ξ_0 is an arbitrary constant.

From equation (1) and (9), we obtain the line element as

$$ds^2 = -dt^2 + \left[Je^{\frac{\eta t^2}{t_*^2}}\right]^2 [dx^2 + dy^2 + dz^2] \quad (14)$$

Using eq. (9), (12), (13) eq. (4), & (5) yields

$$\bar{p} = \left[-\frac{4\eta}{t_*^2}\right] - \left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}})}\right]^{\frac{1}{l}} \quad (15)$$

$$\rho = \left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}})}\right]^{\frac{1}{l}} \quad (16)$$

$$\xi = \frac{1}{\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}} \tag{17}$$

Now, restricting the distribution by considering equation (15) and using eq. (3), the explicit form of physical quantities p, Λ and $\Omega = \frac{\Lambda}{\rho}$ are obtained as

$$p = \left[-\frac{4\eta}{t_*^2} + \frac{6\eta t}{t_*^2\left(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}\right)}\right] - \left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2\left(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}\right)}\right]^{\frac{1}{l}} \tag{18}$$

$$\Lambda = \frac{12\eta^2 t^2}{t_*^4} - \left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2\left(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}\right)}\right]^{\frac{1}{l}} \tag{19}$$

$$\Omega = \frac{\frac{12\eta^2 t^2}{t_*^4} - -\left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2\left(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}\right)}\right]^{\frac{1}{l}}}{\left[-\frac{4\eta}{\alpha t_*^2} + \frac{6\eta t}{\alpha t_*^2\left(\xi_0 + Je^{\frac{\eta t^2}{t_*^2}}\right)}\right]^{\frac{1}{l}}} \tag{20}$$

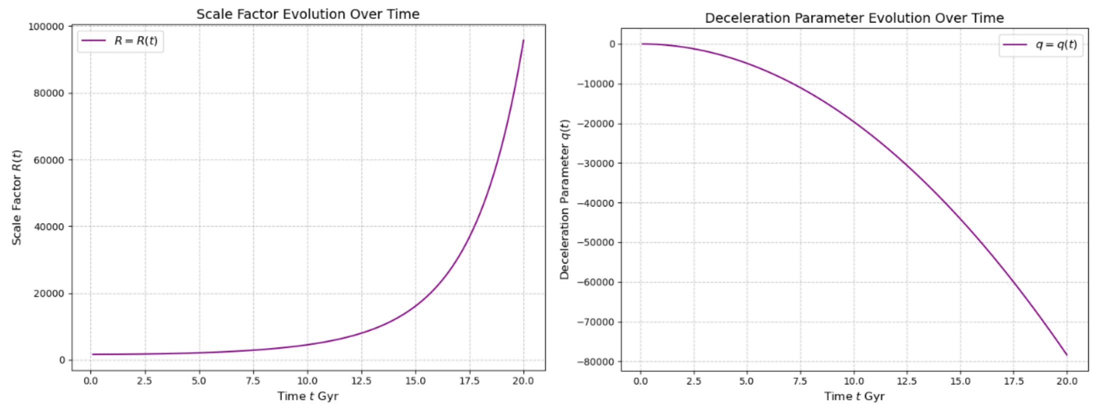

Figure 1: Graph of R & q $vs.$ t

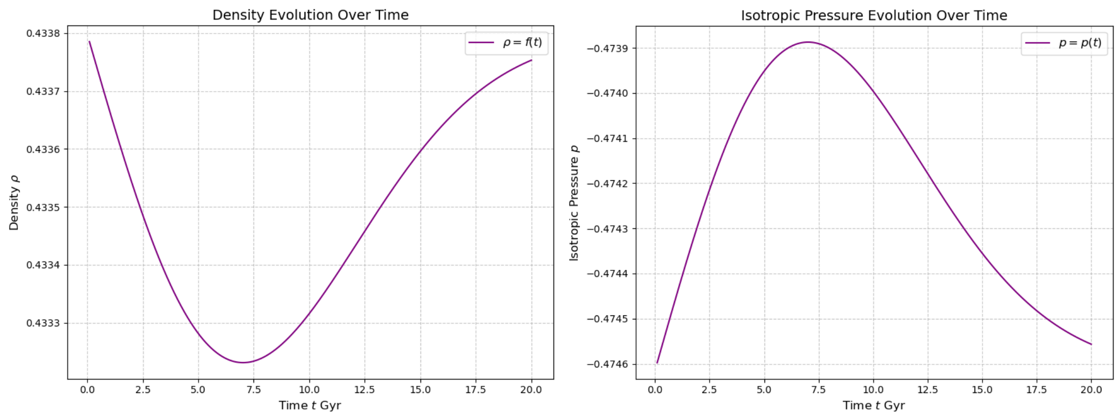

Figure 2: Graph of ρ & p $vs.$ t

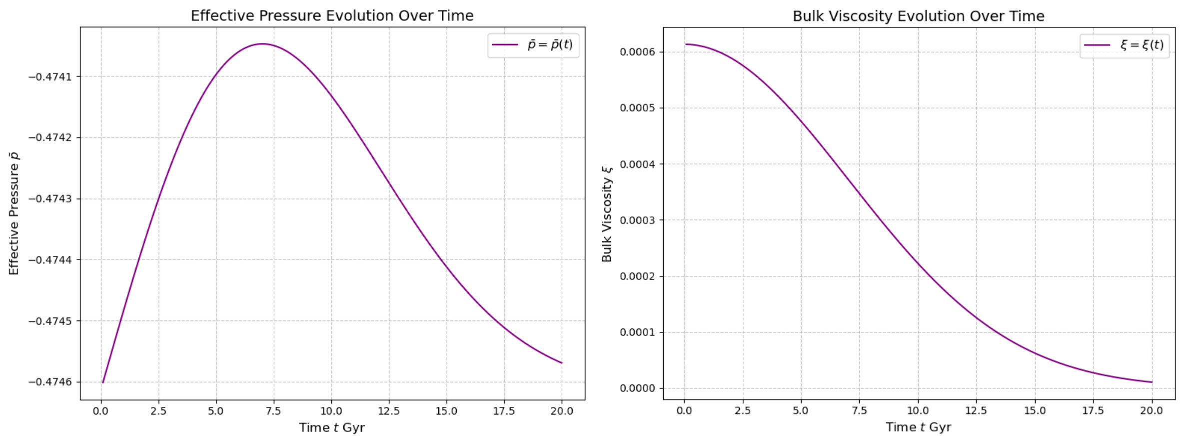

Figure 3: Graph of $\overline{p}$ & ξ $vs. t$

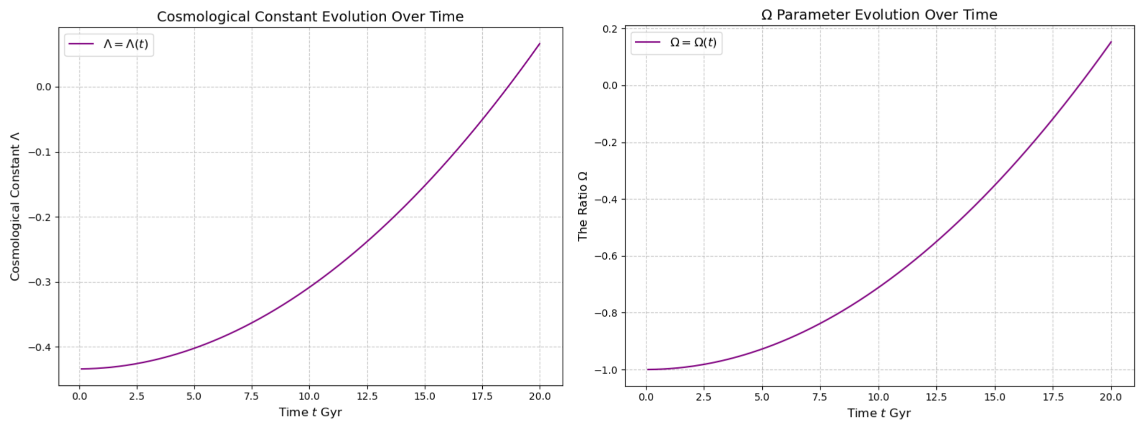

Figure 3: Graph of Λ & Ω $vs. t$

Conclusions:

In this chapter, a particular form of the scale factor $R(t) = Je^{\frac{\eta t^2}{t_*^2}}$ is considered, which gives a varying deceleration parameter. A new exact solution to Einstein's field equations for FRW space-time in the presence of bulk viscosity is found. The scale factor is a positive function that varies over time to describe the changing size of the cosmos, reflecting its expansion dynamics with respect to cosmic time. The model expands over time, and the deceleration parameter shows acceleration in the expansion of the universe [ref Figure 1]. The energy density is positive and remains, so as time increases, it decreases from a very high value at the beginning, then it starts increasing after 7.5 Gyr [ref Figure 2]. The pressure of the models changes in such a manner that they behave as a Dark Energy Model, i.e., in a negative direction [ref Figure 2]. The effective pressure remains in the negative region, and Bulk viscosity starts with a positive value and continuously decreases [ref Figure 3]. It is observed that the cosmological term$-\Lambda$ and the ratio Ω changes with time as in Figure [ref Figure 4]. The present models $t_* = 14, J = 1616, \eta = 2, \xi_0 = 15, \alpha = -0.5, l = 3$ are taken into consideration when drawing figures. In line with the expected behavior predicted by the DE model, the graphical behavior of energy density and pressure shows an inverse relationship between the two variables. Our findings are in agreement with the literature and provide a better understanding of the dynamics of cosmic evolution. Our findings emphasize the soundness of our theoretical framework by showing that cosmic solutions are still possible even when changed factors are taken into account.

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ROLE OF ZINC OXIDE NANOPARTICLES IN WOUND HEALING: BRIDGING SCIENCE AND MEDICINE

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Abstract:

Zinc oxide nanoparticles (ZnO NPs) have garnered considerable interest in biomedical applications, especially in wound healing, owing to their remarkable antibacterial, anti-inflammatory, and regenerative characteristics. ZnO nanoparticles facilitate wound healing by producing reactive oxygen species (ROS) and liberating Zn^{2+} ions, which demonstrate significant antibacterial properties against a wide range of pathogens, consequently diminishing the likelihood of infection. Furthermore, they regulate the inflammatory response, enabling a seamless transition from the inflammatory to the proliferative phase of recovery. ZnO nanoparticles also promote fibroblast proliferation, collagen production, and angiogenesis, which are crucial for tissue regeneration. Their biocompatibility and multifunctional properties render them a promising option for enhanced wound care solutions. This review elucidates the principles and possibilities of ZnO nanoparticles in expediting wound healing and enhancing therapeutic results.

Introduction:

Wound healing is a complex biological process involving multiple phases: haemostasis, inflammation, proliferation, and remodelling. Any disruption in these phases can lead to delayed or non-healing wounds, which pose significant clinical challenges. The development of advanced materials to aid wound healing has become a priority in biomedical research. Among these, zinc oxide nanoparticles (ZnO NPs) have emerged as a promising solution due to their nanoscale properties and bioactivity. ZnO nanoparticles are distinguished by their diminutive size, elevated surface area-to-volume ratio, and distinctive physicochemical features. These characteristics render them exceptionally proficient in engaging with biological systems, particularly in wound contexts. This chapter analyses the applications of ZnO nanoparticles in wound healing, emphasizing their antibacterial, anti-inflammatory, and regenerative properties.

Wound healing is an essential physiological process that allows the body to mend damaged tissues and restore their integrity and functionality following injury. This intricate process is vital for survival, since it mitigates more injury, infection, and loss of tissue functionality. Wound healing entails a meticulously planned sequence of cellular and molecular processes that transpire in overlapping phases, facilitating the replacement of damaged tissue with new, functional tissue.

Upon tissue injury, the body activates a complex sequence of processes to halt haemorrhage, prevent infection, and repair the affected region. The events encompass the interaction of diverse cell types, such as platelets, immunological cells, fibroblasts, endothelial cells, and keratinocytes, alongside the secretion of growth factors, cytokines, and other signalling molecules. The extracellular matrix (ECM) serves a crucial structural and regulatory function, offering a framework for cell movement and attachment while facilitating biochemical signals that promote tissue repair.

The wound healing process is generally divided into four overlapping yet distinct stages:

i) Haemostasis: The prompt reaction to injury, wherein the creation of a blood clot inhibits additional bleeding and establishes a temporary matrix for cellular functions. Inflammation: A protective phase wherein immune cells eliminate infections, debris, and injured tissue, concurrently releasing signalling molecules that attract and activate more cells essential for repair.

ii) Inflammation: A defensive phase in which immune cells clear pathogens, debris, and damaged tissue while releasing signalling molecules that recruit and activate other cells necessary for repair.

iii) Proliferation: A regenerative phase characterized by the formation of granulation tissue, angiogenesis, and the deposition of new collagen and extracellular matrix components.

iv) Re-modelling (Maturation): The final phase, where the new tissue undergoes structural reorganization and strengthening, leading to scar formation and restoration of tensile strength.

The efficacy and results of wound healing are influenced by various factors, including the degree of tissue injury, the individual's age and general health, the existence of comorbidities such as diabetes or vascular disorders, and environmental elements including infection and nutrition. Chronic wounds, which do not heal adequately due to underlying conditions, present considerable obstacles and necessitate specialist treatment.

Progress in the comprehension of wound healing has resulted in breakthroughs in therapeutic procedures, including better dressings, growth factor therapy, and tissue engineering. These advancements seek to improve the natural healing process and mitigate consequences related to compromised or delayed healing.

A comprehensive understanding of wound healing mechanisms is essential for healthcare workers, as it guides the diagnosis, management, and avoidance of problems associated with wounds. It also directs research initiatives in regenerative medicine and biomaterials to enhance patient outcomes in the management of both acute and chronic wounds.

Mechanism of Zinc Oxide Nanoparticles (ZnO NPs) in Wound Healing

ZnO nanoparticles (ZnO NPs) play a pivotal role in wound healing due to their multifunctional properties. Their mechanism of action can be understood across various stages of the wound healing process:

1. Antibacterial Activity

- Mechanism: ZnO NPs release zinc ions (Zn^{2+}), which disrupt bacterial cell membranes, generate reactive oxygen species (ROS), and impair bacterial DNA and protein synthesis.
- Effect: This antibacterial activity reduces infection at the wound site, promoting a cleaner environment for healing.

2. Anti-inflammatory Action

- Mechanism: ZnO NPs modulate pro-inflammatory cytokines (e.g., TNF-α, IL-6) while promoting anti-inflammatory cytokines (e.g., IL-10).
- Effect: They help minimize excessive inflammation, enabling the transition to the proliferative phase of healing.

3. Enhancement of Cellular Migration and Proliferation

- Mechanism: Zn^{2+} ions released from ZnO NPs stimulate keratinocytes and fibroblasts, enhancing their proliferation and migration.
- Effect: This activity accelerates re-epithelialization and the formation of granulation tissue.

4. Angiogenesis Promotion

- Mechanism: Zinc is essential for angiogenesis as it activates vascular endothelial growth factor (VEGF) and related signalling pathways.
- Effect: Improved blood vessel formation ensures better oxygen and nutrient delivery to the wound site.

5. Collagen Synthesis and Extracellular Matrix (ECM) Remodelling

- Mechanism: Zinc activates matrix metalloproteinases (MMPs) and stimulates fibroblasts to enhance collagen synthesis.
- Effect: These processes contribute to ECM remodelling and strengthen the structural integrity of the healed tissue.

6. Oxidative Stress Modulation

- Mechanism: ZnO NPs have antioxidant properties that balance ROS levels, preventing excessive oxidative damage while stimulating healing-related signalling pathways.
- Effect: This dual action protects cells from stress while enhancing repair mechanisms.

7. Controlled Drug Delivery

- Mechanism: ZnO NPs can serve as carriers for therapeutic agents, such as growth factors or antimicrobial drugs, allowing localized and sustained release.
- Effect: This increases the effectiveness of treatments while reducing systemic side effects.

Table 1: Types of Nanoparticles and Their Applications in Wound Healing

Type of Nanoparticle	Composition	Application	Wound Healing Properties
Metallic Nanoparticles	Silver (Ag), Gold (Au), Zinc Oxide (ZnO), Titanium Dioxide (TiO_2)	Antimicrobial, anti-inflammatory, promotes angiogenesis, enhances cell proliferation	Used in wound dressings, prevents infection, accelerates tissue repair
Polymeric Nanoparticles	Poly (lactic-co-glycolic acid) (PLGA), Chitosan, Gelatin, Alginate	Biodegradable, biocompatible, sustained drug release	Delivery of antibiotics, growth factors, and anti-inflammatory agents
Lipid-Based Nanoparticles	Liposomes, Solid Lipid Nanoparticles (SLNs), Nanostructured Lipid Carriers (NLCs)	High biocompatibility, encapsulation of hydrophilic and hydrophobic drugs	Controlled delivery of therapeutic agents like growth factors and antibiotics
Ceramic Nanoparticles	Hydroxyapatite, Silica, Bioactive Glass	High stability, bioactivity, promotes osteogenesis and tissue regeneration	Used in bone-tissue-related wound healing, scaffold for tissue repair
Carbon-Based Nanoparticles	Carbon Nanotubes, Graphene Oxide, Fullerenes	High mechanical strength, antimicrobial, promotes cell adhesion and proliferation	Used in scaffolds for tissue engineering, drug delivery systems

Protein-Based Nanoparticles	Collagen, Silk Fibroin, Elastin	Biodegradable, mimics natural ECM, supports cell growth and migration	Enhances granulation tissue formation, promotes angiogenesis
Magnetic Nanoparticles	Iron Oxide Nanoparticles (Fe_3O_4)	Magnetic properties, targeted drug delivery, imaging capability	Guided drug delivery, real-time monitoring of wound healing
Quantum Dots	Semiconductor materials (CdSe, CdTe)	High fluorescence, allows for imaging and tracking	Real-time monitoring of wound healing, bio-imaging applications

There are several assays used to detect and assess wound healing, each focusing on different aspects of the healing process, such as cell proliferation, migration, and extracellular matrix production. Here are some common assays:

1. MTT assay:

The MTT assay (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) is a colorimetric assay used to assess cell viability, proliferation, and cytotoxicity. This assay relies on the metabolic activity of living cells to convert MTT, a yellow tetrazolium salt, into insoluble purple formazan crystals. The amount of formazan produced is proportional to the number of metabolically active (viable) cells, making it an ideal method for testing cell health and drug effects.

Principle of the MTT Assay:

The MTT assay is based on the ability of mitochondrial enzymes in viable cells to reduce the yellow MTT compound to purple formazan crystals. This reduction occurs because mitochondrial enzymes, such as succinate dehydrogenase, can transfer electrons from NADH or NADPH to the MTT compound, reducing it to formazan. The formazan is insoluble in water, so it must be solubilized in a solvent (e.g., DMSO or isopropanol) before quantification.

Step-by-Step Procedure:

a) Cell Seeding:

- Prepare the culture plate: Seed the cells in a 96-well plate. The density of cells depends on the cell type, typically ranging from 1×10^3 to 1×10^4 cells per well.
- Incubation: Incubate the plate overnight at 37°C in a CO_2 incubator to allow the cells to adhere to the bottom of the wells.

b) Treatment:

- Treat the cells: After the overnight incubation, treat the cells with experimental compounds (e.g., drugs, nanoparticles) for the desired period (e.g., 24, 48, or 72 hours).

- Controls: Include control wells, such as untreated cells (positive control), cells treated with a known cytotoxic agent (negative control), and medium-only wells (blank).

c) MTT Addition:

- After the treatment period, add 10 μL of MTT solution (typically 5 mg/mL) to each well. The final concentration of MTT in each well should be 0.5 mg/mL.
- Gently mix the plate to ensure the MTT is evenly distributed.

d) Incubation:

Incubate the plate for 3-4 hours at 37°C in a CO_2 incubator. During this incubation, metabolically active cells reduce the MTT reagent to purple formazan crystals.

The time of incubation may vary depending on the cell type and experimental conditions, but 3-4 hours is typically sufficient.

e) Solubilization:

After incubation, remove the culture medium containing the MTT solution.

Add 100 μL of DMSO (dimethyl sulfoxide) or isopropanol to each well to dissolve the formazan crystals.

Shake the plate gently for 5-10 minutes to ensure complete dissolution of the formazan crystals. The formazan solution will now have a purple color.

f) Measurement:

Measure the absorbance of the dissolved formazan at 570 nm using a microplate reader. The absorbance is directly proportional to the number of viable cells in the well.

If there are any interference issues with the solvent, a second measurement can be taken at 650 nm to subtract background absorbance.

g) Data Analysis:

Calculate the cell viability by comparing the absorbance of treated cells to the absorbance of control (untreated) cells. A standard formula for calculating cell viability is:

Cell Viability (%) = Absorbance of control (untreated cells)/Absorbance of treated sample ×100; percent Cytotoxicity= 100 – percent Viability.

Alternatively, dose-response curves can be constructed to determine the concentration of a substance (e.g., drug) that inhibits cell proliferation by half (IC50 value).

Advantages of MTT assay:

- Simplicity: The assay is easy to perform and does not require specialized equipment or reagents.
- Quantitative: Provides quantitative data on cell viability and proliferation.
- High Throughput: The assay can be performed in 96-well plates, making it suitable for high-throughput screening.

- Versatility: Can be applied to a variety of cell types, making it widely useful in cell-based research.
- Non-radioactive: Unlike some assays, the MTT assay is non-radioactive, making it safer and more convenient.

Applications of the MTT Assay:

- Drug Screening: Used to assess the cytotoxicity of pharmaceutical compounds, determining their potential for inhibiting cell growth.
- Cancer Research: Helps evaluate the effectiveness of cancer treatments by measuring their effects on tumor cell proliferation and survival.
- Toxicity Testing: Used to evaluate the cytotoxicity of chemicals, environmental pollutants, or nanoparticles.
- Wound Healing Studies: Assesses the effect of various compounds or treatments on cell proliferation and viability, which are crucial in wound repair.
- Regenerative Medicine: Used in testing the effects of growth factors, biomaterials, and stem cell therapies on cell survival and proliferation.

2. Scratch assay:

The scratch assay (also known as the wound healing assay) is a widely used in vitro method to study cell migration, which is a critical component of wound healing and tissue regeneration. This assay simulates the process of tissue repair by creating a "wound" in a cell monolayer and observing how the cells move to close the gap over time. It is particularly useful for assessing the effects of different treatments or compounds on cell migration, which is an essential process in wound healing.

Principle of the Scratch Assay:

The scratch assay works on the principle that when a confluent monolayer of cells is scratched or "wounded," the cells at the edge of the wound will migrate into the gap to cover the empty space. The rate at which the wound closes and the mechanism behind the migration (e.g., chemotaxis, contact inhibition) can be assessed by monitoring the closure over time. The scratch assay is simple and cost-effective, making it a popular method for investigating cellular behaviours like migration and proliferation.

Step-by-Step Procedure:

Cell Seeding:

- Prepare the culture plate: Seed cells in a 6-well or 96-well plate at an appropriate density (typically 1×10^4 to 1×10^5 cells per well) to ensure a confluent monolayer after overnight incubation.
- Incubate the cells: Allow the cells to adhere and form a confluent monolayer by incubating the plate overnight at 37°C in a CO_2 incubator.

Creating the Scratch (Wound):

- Scratch the monolayer: Once the cells have formed a confluent layer, use a sterile pipette tip (usually 200 µL or 1000 µL) or a sterile scraper to create a straight scratch across the monolayer. The width of the scratch should be consistent and typically ranges from 0.5 mm to 1 mm.
- Wash the cells: After scratching, gently wash the plate with phosphate-buffered saline (PBS) to remove any floating cells and debris.

Treatment (Optional):

- Add treatment: After creating the wound, you may treat the cells with specific compounds (e.g., drugs, growth factors, or nanoparticles) to evaluate their effects on cell migration.
- Control wells: Include control wells (untreated cells) for comparison.

Incubation and Monitoring:

- Incubate the plate: Place the plate back in the incubator (37°C, 5% CO_2) and allow the cells to migrate into the wound area.
- Monitor migration: Observe the wound closure over time using a phase-contrast microscope or inverted microscope. Images are typically taken at predetermined time points (e.g., 0, 6, 12, 24, 48 hours).
- If required, image the wound area at regular intervals to monitor the migration progress.

Quantification:

- Image analysis: After the incubation period, use image analysis software (e.g., ImageJ) to measure the area of the wound at different time points.
- Calculate wound closure: Calculate the percentage of wound closure over time. This is typically done by comparing the area of the wound at the start (time 0) with the remaining area at later time points (e.g., after 24 hours). If multiple experimental conditions are tested, compare the rate of wound closure between treated and control cells.

Factors to Consider:

- Cell Type: The scratch assay is typically performed with adherent cell types (e.g., fibroblasts, keratinocytes, epithelial cells), but the cell type can influence the rate of wound closure.
- Confluence: A confluent cell monolayer is necessary for the assay to work effectively. Inconsistent seeding may lead to uneven migration and inaccurate results.
- Scratch Size: The size and width of the scratch can affect the migration rate. Consistency in scratch size is crucial for reproducible results.

- Time Points: Monitoring the wound at different time intervals allows for the observation of cell migration and healing over time. Typically, the wound is monitored for 24 to 48 hours after scratching.
- Inhibitors and Stimulants: Various agents (e.g., growth factors, inhibitors, or drugs) can be added to test their impact on cell migration and wound healing.

Advantages of the Scratch Assay:

- Simplicity: The scratch assay is relatively easy to perform and does not require complex equipment.
- Cost-effective: It is inexpensive compared to other more advanced migration assays, such as transwell migration assays.
- Real-time Monitoring: The assay allows for continuous observation of cell migration and wound closure, which can provide valuable insights into the mechanisms of cell movement.
- High Throughput: It can be performed in multi-well plates (e.g., 96-well), making it suitable for high-throughput screening of different compounds or treatments.

Limitations of the Scratch Assay:

- Cell Density Variation: Uneven seeding of cells or variable confluence levels across wells can lead to inconsistent results.
- Artificial Wound: The scratch does not perfectly replicate natural wound conditions, as cells migrate into a gap, not from an edge of tissue.
- Edge Effect: Cells at the edges of the wound may migrate more quickly than cells in the middle, leading to potential artifacts in analysis.
- No 3D Structure: The assay does not mimic the three-dimensional tissue architecture that is important in real-life wound healing.

Applications of the Scratch Assay:

- Wound Healing Research: To investigate the cellular mechanisms underlying wound closure and tissue repair, including studies on cell migration, proliferation, and ECM production.
- Drug and Treatment Screening: To evaluate the effects of various compounds, such as anti-inflammatory drugs, growth factors, or nanoparticles, on the wound healing process.
- Cancer Research: Used to study cancer cell migration and metastasis by examining how tumor cells migrate into the wound area.
- Tissue Regeneration: To investigate the effects of bio-materials and regenerative therapies on cell migration and tissue repair.

The scratch assay is a simple and powerful tool for studying cell migration, which is central to processes such as wound healing and tissue regeneration. It is widely used in research to understand the effects of different treatments, drugs, and compounds on cell migration and to model wound closure in vitro.

Conclusion:

The MTT and scratch assays collectively offer a thorough insight into the interactions between Zinc Oxide Nanoparticles and fibroblast cells. The MTT assay provides information on cell survival and proliferation, whereas the scratch assay assesses the functional element of wound healing via cell movement. The combination of these experiments highlights the capability of ZnO nanoparticles to stimulate cell proliferation and facilitate wound closure, positioning them as promising candidates for wound healing therapies and tissue engineering applications. Nonetheless, the toxicity profile must be meticulously evaluated, as the concentration of ZnO nanoparticles is crucial in ascertaining their overall performance and safety in therapeutic applications. Consequently, these tests serve as crucial instruments for assessing the biological properties of Zinc Oxide Nanoparticles and their potential to enhance wound healing and regenerative medicine.

Future scope: The future scope of Zinc Oxide Nanoparticles (ZnO NPs) in fibroblast cells and wound healing includes:

1. Targeted Drug Delivery: Enhancing ZnO NP formulations for targeted delivery to wound sites, improving therapeutic efficacy and combining with growth factors or antibiotics.
2. 3D Tissue Engineering: Utilizing ZnO NPs in advanced 3D wound healing models and bio-printed tissues to better replicate in vivo environments and support tissue regeneration.
3. Biocompatibility and Safety: Conducting long-term toxicity studies to assess chronic effects and ensuring the safe use of ZnO NPs in biomedical applications, especially for chronic wound care.

These advancements could improve wound healing, tissue regeneration, and nanomedicine.

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