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A Comprehensive Review of Floristic Diversity Analysis

Deepak Suman* & Poonam Meena*

Keywords – *Biodiversity, Endemic, Floristic Diversity, Rajasthan.*

Abstract

Floristic diversity is a fundamental aspect of biodiversity, representing the variety of plant species across different ecological zones. This review examines the evolution and current state of floristic diversity research, synthesizing findings from global and regional studies, with a particular focus on the Indian subcontinent and the rich biodiversity of Rajasthan. The paper explores methodologies for assessing floristic diversity, challenges in biodiversity documentation, and the impact of environmental changes on plant composition. Special attention is given to recent discoveries, threatened species, and conservation strategies, emphasizing the integration of phylogenetic, ecological, and traditional knowledge-based approaches. By analyzing the interplay between environmental factors, human activities, and plant diversity, this review underscores the need for comprehensive and multidisciplinary strategies for biodiversity conservation. The findings contribute to a broader understanding of floristic diversity patterns and their implications for ecosystem sustainability and human well-being.

Introduction :

Floristic diversity, the variety and distribution of plant species within specific geographical and temporal boundaries, is a fundamental component of global biodiversity. Understanding floristic diversity is essential for assessing ecological dynamics, ecosystem functioning, and the development of effective conservation strategies. Various environmental factors, including climate, soil type, topography, and human activities, shape floristic diversity, influencing the composition and distribution of plant species.

The Indian subcontinent, with its vast and varied ecosystems ranging from tropical rainforests to arid deserts, offers a unique opportunity to study floristic diversity in a regional context.

India is recognized as one of the world's mega-diverse nations, housing approximately 7-8% of all recorded species globally and encompassing 4 (The Himalaya, Indo-Burma, The Western Ghats, and Sunda-land) of the 34 biodiversity hotspots identified worldwide (Tiwari, 2022). The nation is also an important source of traditional knowledge concerning biological resources. As of now, more than 91,200 animal species and 45,500 plant species have been recorded across its ten bio-geographic areas. The Indian desert is home to 682 plant species, more than 6% of which are endemic. In mountainous environments, the percentage of endemic

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vascular plants varies from 32% to 40%. According to the IUCN Red List (version 2010.4), 255 plant species in India are categorized as Critically Endangered, Endangered and Vulnerable. Notably, about 33% of India's plant species are endemic, meaning they are found exclusively within the country (Convention on Biological Diversity [CBD], 2022; India Biodiversity Portal, 2022).In recent years, floristic diversity analysis has gained prominence as a critical field for understanding global biodiversity patterns and their implications for conservation. Researchers have increasingly emphasized the need for comprehensive approaches that integrate global perspectives with regional studies. The Indian subcontinent presents an ideal case for such an approach due to its unique interplay of ecological and cultural factors that shape biodiversity patterns.

As global environmental changes, habitat loss, and anthropogenic pressures continue to threaten plant diversity, the need for detailed floristic studies has become more urgent. Conservation efforts must consider multiple dimensions of diversity, including genetic, species, and ecosystem levels, to ensure sustainable biodiversity management.

Table 1 - Table: Endemic and Total Flowering Plant Diversity in India (KH & Nair, 2020)

Category	**Number of Species**	**Percentage of Total**	**Source**
Total Flowering Plant Species	18,000	100%	Kumar et al., 2022
Endemic Flowering Plant Species	4,900	27%	

This review aims to consolidate existing research on floristic diversity analysis, exploring methodologies, challenges, and future directions. Through the analysis of both global and regional viewpoints, especially within the Indian subcontinent, this research aims to shed light on the intricate relationships between environmental influences, human actions, and plant diversity, ultimately aiding in efforts to conserve biodiversity..

Historical Development of Floristic Studies

The systematic study of plant diversity traces its roots to pioneering works such as Gaspard Bauhin's "*Pinaxtheatribotanici*" (1623), which documented an impressive 6,000 plant species with their synonyms (Cook, 2022). This early attempt at comprehensive plant documentation laid the groundwork for future systematic botanical studies.

Classical Period

The field witnessed significant advancement through the contributions of English botanists Bentham and Hooker. George Bentham (1800-1884), though selftrained, produced several significant monographs on plant families including Labiatae, Arecaceae, Scrophulariaceae, and Polygonaceae (Lawrence, 1955). His publications, notably "Handbook of British Flora" (1858) and the seven-volume "*Flora Australiansis*" (1863-1878), set new standards in botanical documentation (Bentham, 1887; Kraehenbuehl, 1986).

Modern Era Developments

Charles Edwin Bessey (1845-1915) further advanced the field through publications such as "*The Essentials of Botany*" (1884) and "*Synopsis of Plant Phyla*" (1907). Robert F. Thorne's work on the San Gabriel and San Bernardino mountains contributed significantly to regional floristic understanding (Lawrence, 1955).

Global Perspectives

Recent global studies have revealed critical insights into plant diversity patterns and conservation challenges. According to Joppa et al. (2011), over 15% of flowering plant species remain undiscovered, with many facing immediate extinction risks due to habitat loss and global environmental changes.

Worldwide, the preservation of plant diversity encounters various obstacles, such as habitat destruction, shifts in climate, and the introduction of invasive species. These threats are exacerbated in regions like the Indian subcontinent, where rapid urbanization and agricultural expansion have led to significant habitat degradation (Corlett, 2016). Effective conservation strategies must integrate both in situ and ex situ approaches to safeguard plant diversity. For example, methods of ex-situ conservation like seed banks and botanical gardens are essential for maintaining genetic diversity and offering resources for restoration activities (Chapman et al., 2019; Primack et al., 2021). The Millennium Seed Bank initiative exemplifies how ex situcollections can contribute to global conservation efforts by preserving plant genetic resources for future generations (Chapman et al., 2019).

Functional diversity is another critical aspect of floristic studies that warrants attention. It refers to the range of different functions that species perform within an ecosystem, which is essential for maintaining ecological processes and resilience (Freitas & Mantovani, 2017). The structure of vegetation is closely linked to habitat diversity, underscoring the importance of conserving various plant functional groups to support diverse animal communities (Damschen et al., 2019). In the Indian context, the interplay between plant diversity and ecosystem services is particularly pronounced, as many local communities rely on these services for their sustenance and well-being (Masoodi & Sundriyal, 2020).

The role of botanical gardens in conservation and research is increasingly recognized as vital for understanding and preserving plant diversity. These institutions not only serve as repositories for plant species but also engage in research that informs conservation strategies. Botanical gardens in the Indian subcontinent, such as the Indian Botanic Garden in Howrah, have been instrumental in studying native flora and promoting awareness about biodiversity conservation (Chen & Sun, 2018). Furthermore, they facilitate citizen science initiatives that encourage public participation in conservation efforts, thereby enhancing community engagement and education (Kiss et al., 2018). Molecular techniques, including DNA barcoding and genomic studies, are revolutionizing the field of biodiversity research by providing precise tools for species identification and genetic diversity assessment. These techniques enable researchers to uncover hidden diversity and assess the conservation status of plant species more effectively (Mosa et al., 2018).

The concept of ecosystem services is integral to understanding the value of floristic diversity. Plant species offer various ecosystem services, including provisioning services like food and medicine, regulating services involving climate control and water cleanup, and cultural services that provide recreational and spiritual advantages (Corlett, 2016). In the Indian subcontinent, the dependence on non-timber forest products (NTFPs) for economic support underscores the importance of sustainable management practices to guarantee the ongoing availability of these resources (Masoodi & Sundriyal, 2020). Quantitative assessments of the relationship between biological and cultural diversity can inform conservation strategies that align with local needs and practices (Poe et al., 2016).

The impact of climate change on plant diversity is a pressing concern that requires urgent attention. Changes in temperature and precipitation patterns are altering the distribution of plant species and their habitats, leading to shifts in community composition and potential loss of biodiversity (Vellend et al., 2017). In the Indian subcontinent, the susceptibility of native species to climate change highlights the importance of developing adaptive management strategies that take into account future climate scenarios (Stein et al., 2013). Conservation efforts must be proactive, incorporating climate resilience into planning and implementation to mitigate the impacts of environmental change on plant diversity.

Invasive species pose a significant threat to native flora, often outcompeting indigenous plants and disrupting local ecosystems (Litt et al., 2014). The introduction of non-native species can lead to declines in native biodiversity, altering ecosystem dynamics and functions. In the Indian context, managing invasive species through targeted control measures and restoration of native habitats is essential for preserving floristic diversity (Pile et al., 2017). Collaborative efforts among government agencies, NGOs, and local communities are crucial for effective invasive species management and restoration initiatives.

The assessment of extinction risks for plant species is a critical component of biodiversity conservation. The use of herbarium specimens and other historical data is vital for evaluating the conservation status of plant species, particularly in biodiversity-rich regions like the Indian subcontinent (Nic Lughadha et al., 2018). The integration of such data into conservation assessments can inform prioritization efforts and guide resource allocation for species at risk of extinction.

Public awareness and education play a pivotal role in promoting conservation efforts. Involving the community through outreach initiatives, workshops, and educational campaigns can enhance awareness of plant diversity and its significance to human health (Chen & Sun, 2018). In the Indian subcontinent, initiatives that highlight the cultural and medicinal significance of native plants can enhance community involvement in conservation efforts (Rupani & Chavez, 2018). By raising awareness about the threats facing plant diversity and the benefits of conservation, stakeholders can mobilize support for sustainable practices and policies.

The future of floristic diversity analysis hinges on the collaboration between researchers, conservationists, policymakers, and local communities. Multi-disciplinary approaches that integrate ecological, genetic, and socio-economic perspectives are essential for addressing the complex challenges facing plant diversity (Corlett, 2016). Collaborative networks that facilitate knowledge sharing and capacity building can enhance effectiveness of conservation initiatives and promote adaptive management strategies (Leys & Vanclay, 2011) in the Indian subcontinent, fostering partnerships among various stakeholders can lead to more comprehensive and impactful conservation efforts.

Indian Subcontinent: A Floristic Perspective

William Roxburgh (1751-1815) made pioneering contributions to Indian botany, methodically describing approximately 2,600 species and creating over 2,500 botanical illustrations. Hermenegild Santapau's work, including "*Flora of Khandala*" (1953) and "*Flora of Saurashtra*" (1962), further enriched India's botanical literature.

Floristic diversity analysis is a critical aspect of understanding ecological balance and conservation strategies globally, with particular emphasis on the Indian subcontinent, which is recognized as one of the world's biodiversity hotspots. The Indian subcontinent's unique geographical and climatic conditions have fostered a rich tapestry of plant species, making it a focal point for floristic diversity studies. This review synthesizes global perspectives and regional studies, particularly focusing on the Indian subcontinent, to elucidate the complexities and challenges associated with floristic diversity analysis.

The Indian subcontinent is home to approximately 45,000 known plant species, with a significant proportion being endemic to the region. This diversity is attributed to the varied agro-climatic zones and topographical conditions that characterize the area, which provide suitable habitats for a wide range of flora (Patel et al., 2021). The rich ethnobotanical literature highlights the cultural significance of these plant species, which have been utilized for medicinal, nutritional, and ecological purposes throughout history (Rupani & Chavez, 2018). The conservation of this floristic diversity is paramount, not only for ecological balance but also for sustaining the livelihoods of local communities that depend on these resources.

Regional Diversity Patterns

Northeastern India

Studies in Manipur's forests along the Indo-Myanmar border recorded 123 species from 48 families, with *Dipterocarpus tuberculata* as the dominant species. The research noted a higher abundance of shrubs and herbs compared to tree vegetation (Devi & Yadava, 2015). Thanks to the favorable climate and extended protection in the surrounding Sino-Himalayan and Burma-Malayan areas, there is significant species diversity, including 54 endemic species, 31 rare species, and 38 primitive taxa. For the conservation of flora and the benefit of indigenous tribes of the state in these regions it's important to protect them with better management (Pandey & Jamir, 2014).

Southern India

Analysis of the Piranmalai forest in Tamil Nadu revealed varying species richness patterns correlated with disturbance gradients. Undisturbed stands showed the highest species richness, while disturbed areas exhibited the lowest diversity (Pitchairamu et al., 2008). A pantropical species *Crotalaria lanciolata* was reported from Mandya district of Karnataka firstly in india and also provided detailed description, data of distribution and images for identification (Ravikumar et al., 2018).

Conservation Status

Recent studies in Telangana documented 2,078 taxa of Angiospermic plants, comprising 2,001 species across 916 genera and 162 families. Alarmingly, 23.7% are extinct, 8.6% critically endangered, and 11.3% endangered (Chintala, 2019). The floristic work in Telangana provides information of 2078 taxa of angiospermic plants which include 2001 species, 916 genera and 162 families. Among them 23.7% extinct, 8.6% critical endangered and 11.3% endangered species were also reported in forest .

Rajasthan: A Case Study in Regional Floristic Diversity

Geographical and Ecological Context

Rajasthan, India's largest state covering 342,239 square kilometers, presents a unique study area due to its diverse ecological conditions. The state's floristic wealth is influenced by the Aravalli range and distinct climatic zones, from arid western regions to more tropical eastern areas. The expansion of the Indira Gandhi Canal Project has increased population pressure, pushing many species toward extinction (Jakhar et al., 2019). The regions such as desert and snow desert are very vulnerable system of plant vegetation because of resources limitation and most of such area have adverse climatic condition (Ribot et al., 1996).

Conclusion

This review highlights the critical importance of integrating global perspectives with regional studies in the analysis of floristic diversity, with a specific focus on the Indian subcontinent, particularly Rajasthan. The region's rich and diverse plant life provides valuable insights into the intricate ecological, genetic, and socio-economic factors that influence biodiversity patterns. By highlighting the unique challenges faced by Rajasthan's flora, this review emphasizes the need for innovative methodologies that combine scientific research with traditional ecological knowledge. As threats to biodiversity continue to mount, it is crucial to prioritize conservation efforts that reflect the region's distinctive ecological dynamics and the role of local communities. Future research should continue to bridge the gap between global conservation strategies and regional realities, ensuring sustainable management of plant diversity for both ecological and socio-economic benefits.

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Isolation and Biochemical Characterization of Bacteria from Paddy Soils of Nabinagar, Aurangabad District (Bihar)

Md. Haider Imam

Keywords : *YEMA media, Rhizospheric soil, IMViC test, Bacillus sps.*

Abstract

The current study revealed the isolation and characterisation of bacterial strains from the rhizosphere of a rice plant in Nabinagar, Aurangabad (Bihar). The morphology of isolated bacteria was determined using Gram's staining. The bacterial isolates were also biochemically characterised using a variety of procedures such as the IMViC test and the catalase test. *Bacillus* sp, *E. coli*, *Azotobacter* sp., *Pseudomonas* sp., and *Rhizobium* sp. were among the microorganisms found in paddy soil. *Bacillus* sp. have a substantial influence on the nitrogen cycle. In the current study, diazotrophs such as *Rhizobium* and *Azotobacter* were identified from the rhizosphere soil of paddy fields. These data revealed microbial diversity in the rice plant rhizosphere.

INTRODUCTION

Rice (*Oryza sativa*) is a major commercial crop that has been grown for over 7000 years and constitutes a steady food source in many parts of the world [Lakshmanan *etal.,* 2015]. Over a billion people rely on rice agriculture for sustenance, and more than 3.5 billion people eat rice for more than 20% of their daily calories. Rice is known to grow in watery areas. The upper surface density of paddy soil is regarded as critical for successful crop production [Kazemi *et al.,* 2010]. Paddy field soil is rich in organic matter, including old stubble, paddy straw, senescent roots, and trash. Various soil bacteria help to breakdown soil organic materials including paddy straw. Soil and water in rice fields have a significant impact on the bacterial community.

Microorganisms in paddy fields provide important functions such as methanogenesis, methane oxidation, and biogeochemical cycles. These cycles consist of five major processes: nitrogen fixation, nitrogen absorption, nitrogen mineralisation, nitrification, and denitrification. Microorganisms, particularly bacteria, play important roles in the main processes of carbon, nitrogen, and sulphur transformations [Shi *et al.,* 2021].

Soil has a diverse range of bacterial and fungal organisms. Soil microorganisms have an important role in carrying out several metabolic events in soil, such as the breakdown of soil organic nitrogen and the decomposition of rice straw and compost applied to the soil [Tang *et al.,* 2021].

These processes are critical for increasing rice yield and maintaining paddy soil fertility. Nitrogen is a critical component of the biogeochemical cycle that determines the conversion of nitrogen and nitrogen-containing compounds in

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agricultural areas [Prosser *et al.,* 2020]. Bacteria and fungus are the primary contributors in well-oxygenated soils, whereas bacteria are responsible for the majority of chemical and biological transformations in oxygen-depleted soils.

The rhizosphere is the soil zone closest to the surface of a plant's root [Morgan *et al.,* 2005]. The rhizosphere is colonised by a massive and diversified microbial community, with microbial total density potentially exceeding the cell density of the plants [Barea *et al.,* 2005]. Rhizospheric bacteria have a wide range of agricultural applications. Plant Growth Promoting Rhizobacteria (PGPR) is employed in agriculture as insecticides and fertilisers, as well as to improve plant health and production (Josic D and Spomenka K, 2008). In this context, rice plant rhizospheric soil may support a diversified microbial population with industrial and agricultural applications (Muangham *et al.,* 2019). The current work has been completed with all of the aforementioned considerations in mind.

MATERIALS AND METHODS

Collection of soil sample:

The soil sample was collected from a paddy field in Nabinagar (24.62°N, 84.12°E), district Aurangabad, Bihar. The adhering soils from the root sections were carefully removed, collected in a sterile petriplate, and sent to the laboratory for further investigation.

Processing of soil sample:

The soil microorganisms were isolated using the serial dilution approach. First, one gram of soil from the sample was suspended in 10 ml of sterile saline solution, stirred thoroughly for 15 minutes, and vortexed. The suspension was serially diluted from 10-1 to 10-4 to produce well-defined colonies on petriplates.

Isolation of Bacteria:

In this investigation three media namely Ashby's Medium; YEMA and NAM were used for the isolation of bacteria

Characterization of Bacteria:

Gram stains were used to determine the morphology of bacteria. The bacterial isolates were biochemically characterised using several tests such as indole, MR, VP, citrate, and catalase [Harold *et al.,* 2002].

Result

In the current study, both gram-positive and gram-negative bacteria were isolated from rice fields.

Table 1: Morphological properties of isolated bacteria from paddy soil.

Bacteria	Shape	Arrangement	Staining Characteristics
Bacillus	Rod	Chain	Gram positive
E. coli	Rod	Rods	Gram negative
Azotobacter	Oval	Clusters	Gram negative
Pseudomonas	Rod	Slender	Gram negative
Rhizobium	Rod	Single	Gram negative

Table 2: Biochemical examination of microorganisms found in paddy soil.

Bacterial species	Indole	MR	VP	Citrate	H_2S production	Catalase
Bacillus	-	-	+	+	+	+
E. coli	+	+	-	-	-	+
Azotobacter	+	-	+	+	+	+
Pseudomonas	-	-	-	+	-	+
Rhizobium	-	-	+	-	-	+

(+) : Positive (-) : Negative

Bacillus, E. coli, Azotobacter, pseudomonas, and Rhizobium bacteria were detected in paddy soil samples based on biochemical features. One isolated gram-positive bacteria was identified as Bacillus (Table -1). The results of biochemical characterisation are summarised in Table 2.

Growth of *Azotobacter* on Ashby's Medium

Growth of Rhizobium on YEMA Medium

Positive Catalase Test

Positive Indole Test by Azotobacter

Discussion:

Oryza sativa is a cereal food crop from the Poaceae family of the Plant Kingdom. This crop is easily grown in tropical regions with humid climate. The current work aimed to extract and identify bacteria from rice fields in order to gain insight into the microbial diversity of rice plant rhizospheres. These strains demonstrated a variety of morphological and biochemical features (Tables -1 and -2), showing that they belong to the genera *Bacillus Escherichia*, *Azotobacter*, *Pseudomonas*, and *Rhizobium*. Several studies have identified various bacterial species from rice plants. *Bacillus* sp. is often found in soil and have a major impact on the nitrogen cycle, hence increasing soil fertility [Guerrieri *et al.,* 2020].

In the current study, nitrogen-fixing bacteria such as *Rhizobium* and *Azotobacter* were identified from paddy field rhizospheric soil. Isolation of nitrogen-fixing bacteria was performed on selective media Yeast Extract Mannital Agar (YEMA) is also referred to as Ashby's medium. Bacterial growth on YEMA indicates their potential to fix atmospheric nitrogen either independently or symbiotically with plants. Some researchers have previously reported on the use of YEMA to isolate nitrogen-fixing bacteria [Pervin *et al.,* 2017, Rosemary *et al.,* 2013].

In the current analysis, a paddy soil sample revealed the presence of *pseudomonas* species. *Pseudomonas* species are currently receiving a lot of attention from researchers in sustainable agriculture because of their contribution to plant growth promotion and induced resistance via various modes of action such as disease suppression, improved nutrient acquisition, and phytohormone production. *Pseudomonas* is ubiquitous in soil ecosystems due to their metabolic versatility and genetic plasticity. They are common inhabitants of the rhizosphere of numerous agricultural crops, where they play an important role in plant growth promotion and biocontrol agents that are better suited to plant growth, yields, and disease management (Jain R, Pandey A, 2016).

Kannan et al., (2018) found that prevalent soil bacteria included *E. coli, Micrococcus* sp., *Escherichia* sp., and *Staphylococcus* sp. The present finding is quite similar to that of Kannan et al., (2018). Sharma et al., (2013) isolated *Bacillus, Streptomyces,* and *Rhizobium* spp. from the rice rhizosphere. *Bacillus* and *Rhizobium* spp. were also found in the rice rhizosphere. According to Chowdhary et al. (2013), *Bacillus* sp. is the most common bacterium in agricultural soil in Bangladesh. The current report substantially paralleled the findings of Chowdhary *et al,* (2013).

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Exploring the Forensic Significance of Diatoms : A Review

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Keywords : *Diatoms, Drowning Investigation, Forensic Science, Water Bodies.*

Abstract : Diatoms have emerged as a critical tool in forensic science, particularly in investigating drowning cases. Their forensic significance stems from their ubiquitous presence in water bodies and their unique ability to be incorporated into the human body in drowning scenarios. This article explores the importance of diatoms in forensic investigations, particularly in the context of drowning, and their use as evidence to establish the cause and time of death. It delves into their morphological characteristics, methods of analysis, challenges in interpreting diatom evidence, and the integration of diatom analysis into forensic protocols. This review also highlights various studies, techniques, and advancements in diatom research and their implications for forensic science.

Introduction

Diatoms are non-motile, unicellular microalgae. They are the most common type of phytoplankton which belong to the kingdom of Protista and are classified under Bacillariophyceae. Diatoms are the most successful organisms that can thrive in large numbers in almost every aquatic environment. They are also in charge of fixing carbon in the atmosphere.The typical size of diatoms is between 10 and 20 µm (Petar et al., 2014). Their silica-based cell wall hardens the cells' exterior lining. The siliceous covering of the cell is inert and indestructible too (Verma, 2013).

Diatoms are broadly classified into two categories based on their structure: Centrales and Pennales. Centric diatoms are radially symmetrical, found drifting near the surfaces of the water and are wheel shaped whereas pinnate diatoms are laterally symmetrical and live in fresh water streams, swamps, or bottoms of shallow water (Saxena et al., 2021). Over 10,000 different species of diatoms have been identified. As a result, they are different in size and shape. These microbes are useful for diagnosing drowning death because of these variations (Plenkovic-Moraj et al., 2007).

During the investigation, it was frequently observed that the perpetrators disposed of the body in water to simulate the cause of death and create a suspicion of suicide. Water enters the respiratory tract during drowning because of a battle for the expiratory process. The diatoms could only be transported from the lungs by a living organism with active circulation, which would shatter the alveolar wall and allow them to go through the lymph nodes, pulmonary veins, left-side heart, and systemic circulation, which includes the kidney, brain, and bone marrow(Round, 1991).

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Examining these samples and determining the cause of death is a difficult task for a forensic pathologist. However, the presence of diatoms makes it possible to determine whether the death happened before to or following drowning (Piette & Els, 2006). This review covers the physical traits of diatoms, analysis techniques, difficulties in interpreting diatom evidence, and how diatom analysis is incorporated into forensic procedures. A number of diatom studies, methods, and developments are also highlighted in this review, along with their significance for forensic science.

Morphological Characteristics of Diatoms

The unique morphological features of diatoms make them particularly useful in forensic investigations. Diatoms are characterized by their rigid silica cell walls, or frustules, which are often elaborately patterned. These frustules consist of two halves, or valves, that fit together like a petri dish, with an intricate, species-specific design. The patterns on diatoms are so detailed that they can be used to identify specific species and even distinguish between diatoms from different water bodies (Krammer & Lange-Bertalot, 1991).

The primary morphological characteristics that are used to identify diatoms include the shape of the frustules, the arrangement of the pores, and the overall symmetry of the structure. There are thousands of diatom species, and each one has unique characteristics, such as its size, shape, and ornamentation. These characteristics are important in forensic analysis as they allow forensic experts to match diatom species found in the body with those in the surrounding water environment.

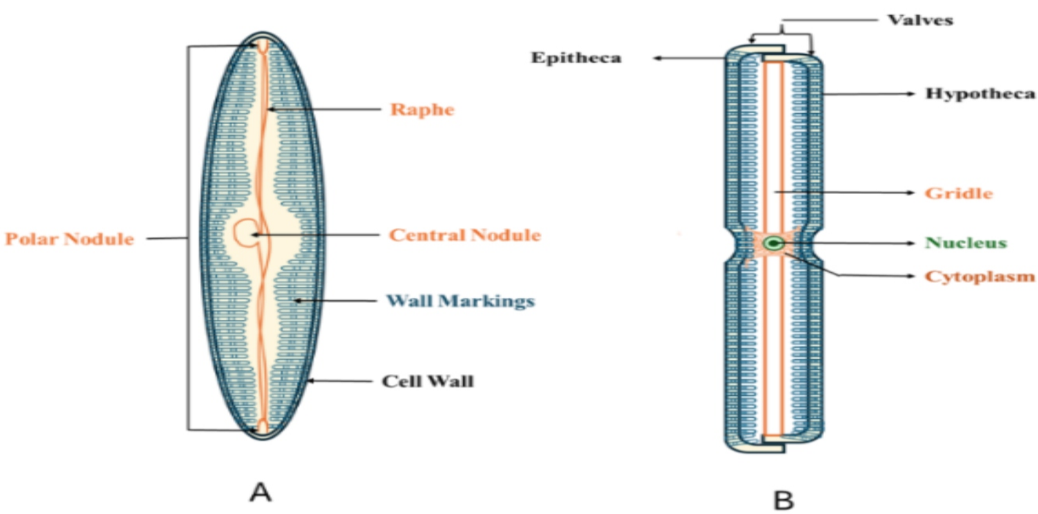

Figure : Cell structure of diatoms :
A. Frustule in valve view. B. Frustule in girdle view.

Diatoms and Drowning

Drowning occurs when a person's airway is obstructed by water, leading to a lack of oxygen and ultimately death. During the drowning process, water is aspirated into the lungs, and depending on the location of the drowning, different species of diatoms may be introduced into the body. The forensic value of diatoms lies in their ability to be regionally specific, meaning that diatom species found in the lungs can be matched to the water body where the drowning occurred (Stojanovic, 2018).

When a drowning victim examined by forensic experts, often examine the lungs, stomach, and other internal organs for the presence of diatoms. The primary method for detecting diatoms in the body is through microscopic analysis, where a forensic pathologist can compare the diatom species found in the victim's lungs with those found in the water at the scene of the drowning (Piette & Els, 2006). If the species match, it strengthens the case for drowning as the cause of death. Additionally, diatom analysis can help differentiate between drowning and asphyxiation.

Examination of organs for presence of diatoms

The qualitative and quantitative diagnosis of the presence of diatoms in suspected drowning cases is aided by the successful completion of the definitive tissue analysis. Each organ has a different distribution of diatoms, so the forensic scientist must choose the right specimen for the examination. For many years, the study was typically done utilizing the heart, liver, blood, lungs, bone marrow, long bones, and so on. According to a control experimental investigation conducted on laboratory rats to count the number of diatom cells in each organ, the stomach and lungs had the most diatom cells since water entered these organs directly through the mouth and nostrils (Krstic et al., 2002).Samples are taken and maintained with the use of appropriate preservatives throughout the postmortem assessment. It was discovered that the formalin used to fix the lung tissue during the autopsy worked well. The samples preserved using formalin can be utilized for long-term examination purposes as these microorganisms resist putrefaction (Takeichi & Kitamura, 2009). Formalin, however, is not advised for preservation since it ruins the delicate cell structure. Lugol's iodine solution or ethanol should be used to preserve the control samples that were gathered for the examination procedure(Taylor et al., 2007).

Diatoms can be isolated and examined using a variety of techniques in forensic investigations. Using a microscope to examine bodily fluids, such as blood, stomach contents, or lung tissue, is one of the most popular methods. Chemical digestion is frequently employed to separate diatoms from these fluids. This method uses powerful acids or alkalis to break down the organic material, leaving the diatoms intact for analysis.

Table : 1 - Different methods of extraction for diatoms and their procedures

Extraction Method	Procedure
Digestion of acids	It is among the earliest methods of diatom extraction that are still in use today. This approach uses nitric acid to digest the tissue. After that, the residue is centrifuged to create a pellet. These pellets are made of material that is resistant to nitric acid and are subsequently applied to a microscope slide for additional analysis (DiGiancamillo et al., 2011). An instrument known as "can" was created to get around the practical issue. The process includes using a strong acid to liquidate the tissue and then heating it at a high temperature(Yange et al., 1999). This instrument is unique in that it is easy to use, takes less time, and is more efficient (Ludes et al., 1994).
Digestion by enzymes	With this technique, proteinase K is applied. After chopping the tissue sample, it is washed in a solution of proteinase K and Tris HCl buffer. The sample is centrifuged after the solvent has been incubated for the entire night. After that, the solid residue is taken out and examined under a microscope that has been mounted with Naphrax (Charles et al., 2002).
Extraction	The extraction process of soluene-350 works well for freshwater diatoms. After three rounds of washing with distilled water, the tissue sample is centrifuged. After being collected, the residue is suspended in a solution of Soluene-350 and left to incubate overnight at room temperature. After centrifuging this solution, the pellet that is produced is applied to a microscopic slide and examined under a light microscope(Sidari et al., 1999).
Microwave digestion	This is extremely sensitive diatom extraction technique. A microwave digestion device that contains a combination of tissue sample and acid solution is used to break down the sample. There is minimal pollution, and the method is quite effective. After digestion, the solution is examined using a SEM.

In some cases, forensic scientists may use molecular techniques, such as DNA analysis or polymerase chain reaction (PCR), to identify diatom species more precisely. The type of bodily fluid being studied, the sample's state, and the equipment available all influence the analytical procedure selection. However, the requirement for reference samples is one of the biggest obstacles in diatom analysis. Forensic specialists need to have access to a database of local diatom species in order to compare those from the victim's body with those from the alleged drowning site. In situations when the drowning happened in an area with little diatom reference data, this can be especially difficult.

Challenges in Diatom Analysis

Despite its potential for forensic application, diatom analysis have many challenges. One of the major difficulties in using diatoms as evidence is the need for accurate and reliable reference data. To match diatom species found in the victim's body with those found in the water, forensic scientists need to have access to detailed databases of diatom species from various water bodies. This requires the collection and identification of diatom samples from a wide range of geographical locations and water types, which can be time-consuming and resource-intensive (Verma, 2013).

Moreover, the discovery of diatoms in the body does not always prove drowning. Diatoms can occasionally be discovered in the lungs or other organs as a result of contamination, aspiration during resuscitation attempts, or the presence of water in the victim's surroundings in their final moments (Singh et al., 2006). When evaluating diatom evidence, forensic specialists must also carefully take into account additional elements, such as the victim's medical history and the circumstances surrounding the death.

The diversity of diatom populations in various aquatic habitats presents another difficulty. Depending on the season, diatom communities can change greatly throughout water bodies. Due to this diversity, it may be challenging to match diatom species from the drowning site with those discovered in the victim's body, especially if the water body is big or far away.

Advancements in Diatom Research

The possibility for forensic analysis has increased due to recent developments in diatom research. The application of molecular techniques to identify diatom species is one of the most promising areas of development. Forensic scientists may identify diatoms at a molecular level using methods like DNA barcoding and high-throughput sequencing, which may help them get around some of the drawbacks of conventional morphological examination (Girela-López et al., 2020).

Furthermore, advancements in computational tools and software have made it easier to analyze diatom populations and compare them to reference databases. These tools can automate the identification of diatom species based on morphological features, significantly speeding up the analysis process and improving accuracy(Dixit et al., 1992).

Conclusion

Diatoms are essential to forensic science, especially when it comes to suspected drowning cases. They are useful evidence for identifying the cause and location of death because of their capacity to endure in a variety of aquatic conditions and their distinctive, species-specific shape. The precision and dependability of diatom analysis have increased due to developments in molecular techniques and computational tools, despite obstacles like the necessity for reference databases and the fluctuation of diatom populations. The use of diatoms as forensic evidence is probably going to become increasingly more important in the examination of drowning cases as forensic science develops.

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From Ancient Practices to Modern Play : Plants for Sports Performance Enhancement

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Keywords – *Herbal supplements, Plant, Sports, Traditional uses, Therapeutic.*

Abstract

Plants have been used to enhance athletic performance for centuries, with their roots in ancient traditions across cultures. This review examines the historical use, modern scientific evidence and current applications of plant-based supplements in sports. From ancient Egypt to the Greek Olympic Games, plants played a key role in improving strength, endurance and recovery. Today, scientific studies are validating these traditional uses, with herbs like *Panax ginseng* and *Tribulus terrestris* showing potential benefits in reducing muscle damage and supporting recovery. However, the growing popularity of herbal supplements also raises concerns about their safety, effectiveness, and the lack of strict regulations in the market. Globalization has influenced sports practices, often sidelining traditional methods, but efforts to integrate ancient knowledge with modern training are gaining momentum. This review highlights the importance of combining traditional wisdom with scientific research to create safe and effective plant-based solutions for athletes, offering a balanced way to enhance performance while respecting cultural traditions.

Introduction

The connection between ancient practices and modern sports enhancement through plants is an interesting area of study, showing how human creativity has always aimed at improving athletic performance. In the past, athletes looked for different ways to boost their performance, with plants playing an important role. The use of plants for improving strength, endurance, and recovery goes back to ancient times when athletes used herbal mixtures and natural substances for these benefits. The ancient Greeks and Romans used herbs and animal extracts to improve their athletic abilities, showing that the use of natural methods for sports performance has been a long-standing tradition(1).

Today, the use of plant-based supplements has become more popular, as athletes and fitness enthusiasts increasingly turn to herbal remedies to improve their performance. The modern sports nutrition market is full of products made from plants, showing growing recognition of their potential benefits. Studies on plants such as ginseng suggest they may enhance performance, though the scientific evidence regarding their effectiveness remains inconclusive (2, 3). Additionally, the growing market for these supplements has resulted in a surge of products, prompting concerns about their purity, safety, and possible side effects(4, 5).

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The need for strong scientific evidence makes the use of plants in sports performance more complicated. While many athletes use herbal supplements, the lack of standard testing and regulation in the industry can create risks, such as contamination with banned substances or the inclusion of unverified ingredients (5, 6). This emphasizes the importance of thorough research to evaluate the safety and effectiveness of these plant-based supplements. It also highlights the need for athletes to be well-informed consumers in a market often driven more by marketing than by solid scientific proof (4, 6). Combining traditional knowledge with modern science offers an exciting opportunity to improve our understanding of plant-based performance boosters. For example, research on plant like Ashwagandha is starting to show their potential in reducing oxidative stress and improving athletic performance (7, 8). This approach, which blends traditional methods with current scientific research, could lead to the creation of new, evidence-based supplements that respect both the historical use and the scientific standards needed for safe performance enhancement in athletes.

The use of plant-based nutrition in sports performance enhancement has a long history, from ancient practices to modern times. While natural performance enhancers are still popular, but it is now important to focus on their safety, effectiveness, and scientific support. The combination of traditional knowledge and modern research will continue to create the future of sports nutrition, helping athletes improve their performance while respecting past traditions.

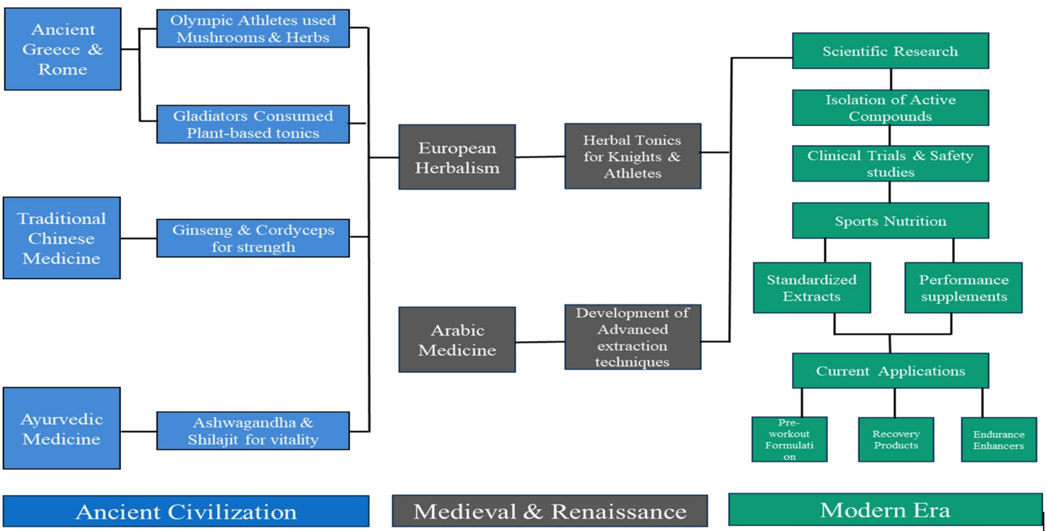

Figure 1 The Evolution of Plant-Based Performance Enhancement : A Journey from Ancient Athletics to Modern Sports Nutrition"

Role of plants in sports performance enhancement The role of plants in sports enhancement has garnered significant attention, particularly in the herbal supplements reference that athletes utilize to improve performance and recovery. The growing use of these natural products is partly because they are seen as a safer option compared to synthetic drugs, particularly with strict regulations from organizations like the World Anti-Doping Agency (WADA) (9, 10). Herbal supplements, such as Panax ginseng and Tribulus terrestris have been studied for their potential benefits in athletic performance enhancement and aiding recovery from exercise-induced muscle damage (EIMD) (11, 12).

Research indicates that heavy and excessive exercise can lead to muscle damage characterized by inflammation and oxidative stress, which negatively impacts athletic performance. Herbal supplements have been proposed to mitigate these effects. For example, Panax ginseng has shown the potential to improve metabolic health and exercise performance by modulating blood lipid profiles and energy consumption during physical activity (11). Similarly, Tribulus terrestris is being studied for its potential as an antioxidant and anti-inflammatory, which may help reduce the symptoms of exercise-induced muscle damage and improve overall performance (12).Many athletes report using herbal supplements, but the purity and efficacy of herbal supplements can vary significantly, raising concerns about their safety and potential side effects (4, 13). This lack of understanding about herbal supplements can lead to unintended doping violations, as some herbal supplements may contain prohibited substances (14).

Furthermore, the popularity of herbal supplements among athletes is reflected in various studies that explore their usage patterns. For example, a collegiate athlete survey revealed that many athletes resort to herbal products for performance enhancement, despite the limited scientific evidence supporting their efficacy (2, 4). This type of perception of supplements is natural and thus safer alternatives to conventional drugs continues to drive their use, despite the potential risks associated with their consumption (10).

Table 1 Traditional uses of plants in sports performance enhancement

S.No.	**Plant Name**	**Traditional Use**	**Mechanism of Action**	**Cultural Context**	**Ref.**
1.	*Curcuma longa* (Turmeric)	Anti-inflammatory properties to reduce muscle soreness.	Curcumin inhibits inflammatory cytokines, aiding recovery.	Widely used in Ayurvedic medicine for its beneficial impacts on health.	(15)
2.	*Morinda citrifolia* (Noni)	Boosts energy and endurance during physical activities.	Contains antioxidants and compounds that may enhance stamina.	Used in Polynesian cultures for its health-promoting properties.	(16)
3.	*Zingiber officinale* (Ginger)	Reduces muscle pain and soreness post-exercise.	Anti-inflammatory effects help in recovery.	Commonly used in various traditional medicines for its medicinal properties.	(17)
4.	*Panax ginseng (Ginseng)*	Enhances physical performance and reduces fatigue.	Adaptogenic properties improve stamina and recovery.	Used in Traditional Chinese Medicine system for vitality and energy.	(11)

5.	*Withania somnifera* (Ashwagandha)	Improves strength and reduces stress.	Adaptogenic effects help in managing stress and enhancing physical performance.	Integral to Ayurvedic practices for promoting overall health.	(18)
6.	*Echinacea purpurea (Purple cone flower)*	Supports immune function during intense training.	Enhances immune response, reducing illness risk.	Traditionally used by Native Americans for different health benefits.	(19)
7.	*Rhodiola rosea (Golden root)*	Increases endurance and reduces fatigue.	Enhances energy metabolism and reduces perceived exertion.	Used in traditional Siberian medicine for stamina and resilience.	(20)
8.	*Tribulus terrestris (Gokhru)*	Enhances libido and may improve athletic performance.	Increases testosterone levels, potentially improving strength.	Commonly used in traditional medicine for vitality.	(21)
9.	*Allium sativum* (Garlic)	Improves cardiovascular health and endurance.	Contains allicin, which may enhance blood flow and reduce fatigue.	Used in various cultures for its health benefits.	(22)
10.	*Camellia sinensis* (Green Tea)	Boosts metabolism and aids in fat oxidation.	Contains catechins that enhance metabolic rate.	Consumed globally for its health-promoting properties.	(23)
11.	*Ginkgo biloba (Maiden hair tree)*	Improves blood circulation and cognitive function.	Enhances blood flow, potentially improving endurance.	Used in traditional Chinese medicine for cognitive enhancement.	(24)
12.	*Cissus quadrangularis (Veldt grape)*	Supports joint health and recovery.	Contains flavonoids that may reduce inflammation and promote healing.	Traditionally used in Ayurvedic medicine for bone and joint health.	(25)
13.	*Boswellia serrata (Salai)*	Reduces inflammation and pain in joints.	Boswellic acids inhibit inflammatory pathways.	Used in Ayurvedic practices for its anti-inflammatory properties.	(26)
14.	*Aloe vera (Ghrit kumari)*	Aids in recovery and hydration post-exercise.	Contains vitamins and minerals that support recovery.	It is used traditionally for its soothing and healing properties.	(27)
15.	*Schisandra chinensis (Schisandra)*	Enhances endurance and reduces fatigue.	Adaptogenic properties improve physical performance.	Part of Traditional Chinese Medicine system for its vitality and endurance capacity.	(28)

16.	*Silybum marianum* (Milk Thistle)	Supports liver health and detoxification.	Contains silymarin, which may enhance recovery by supporting liver function.	Traditionally used for liver health in various cultures.	(29)
17.	*Urtica dioica* (Nettle)	Reduces inflammation and supports recovery.	Contains anti-inflammatory compounds that aid in recovery.	Used in traditional European herbal medicine for its health benefits.	(30)
18.	*Moringa oleifera (Drumstick tree)*	Boosts energy and nutrient intake.	Rich source of minerals and vitamins that support overall health.	Used in various traditional systems for its nutritional value.	(31)
19.	Caffeine (from various plants)	Enhances focus and endurance during exercise.	Stimulant effects improve performance and reduce perceived exertion.	Commonly consumed in various cultures for its energizing effects.	(32)
20.	*Eleutherococcus senticosus* (Siberian Ginseng)	Enhances endurance and reduces fatigue.	Adaptogenic properties improve physical performance and recovery.	Used in traditional Siberian medicine for stamina and resilience.	(33)
21.	*Taraxacum officinale* (Dandelion)	Supports liver health and detoxification.	Diuretic properties may aid in recovery and reduce bloating.	Used in various traditional systems for its health benefits.	(34)
22.	*Gymnema sylvestre (Gurmar)*	May enhance endurance and reduce fatigue.	Contains gymnemic acids that may improve energy metabolism.	Used in traditional Indian medicine system for various health benefits.	(35)
23.	*Passiflora incarnata* (Passion Flower)	Reduces anxiety and promotes relaxation.	Anxiolytic effects may improve focus and performance.	Part of traditional herbal medicine for its calming properties.	(36)
24.	*Salvia officinalis* (Sage)	Enhances cognitive function and focus.	Contains antioxidants that may improve mental clarity.	Used in various cultures for its medicinal properties.	(37)
25.	*Cinnamomum verum* (Cinnamon)	Improves blood sugar control and energy levels.	May enhance insulin sensitivity, supporting energy metabolism.	Used in various traditional systems for its health benefits.	(38)
26.	*Vaccinium myrtillus* (Bilberry)	Supports eye health and improves vision.	Contains anthocyanins that may enhance visual acuity.	Used in traditional European herbal medicine for eye health.	(39)

27.	*Mentha piperita* (Peppermint)	Enhances focus and reduces fatigue.	Aromatic properties may improve cognitive performance.	Used in various cultures for its refreshing and stimulating effects.	(40)
28.	*Artemisia absinthium* (Wormwood)	Traditionally used for digestive health.	May enhance digestion, supporting overall health.	Utilized in various traditional systems for its medicinal properties.	(41)
29.	*Morus alba* (White Mulberry)	Supports blood sugar control and energy levels.	Contains compounds that may improve insulin sensitivity.	Part of traditional Chinese medicine system for its health benefits.	(42)
30.	*Fucus vesiculosus* (Bladderwrack)	Supports thyroid function and metabolism.	Iodine content may enhance metabolic rate.	Used in traditional herbal medicine for its nutritional value.	(43)
31.	*Trigonella foenum-graecum* (Fenugreek)	Enhances testosterone levels and strength.	May improve muscle mass and strength.	Used in traditional Indian medicine system for various health benefits.	(44)
32.	*Carya ovata* (Shagbark Hickory)	Provides energy and endurance.	Rich in nutrients that support overall health.	Used in various traditional systems for its nutritional value.	(45)
33.	*Rubus idaeus* (Raspberry)	Supports recovery and reduces inflammation.	Contains antioxidants that may aid in recovery.	Used in traditional herbal medicine for its health benefits.	(46)
34.	*Satureja montana* (Savory)	Enhances digestion and nutrient absorption.	May improve digestive health, supporting overall performance.	Utilized in different cultures for its culinary and therapeutic qualities.	(47)
35.	*Eucalyptus globulus* (Eucalyptus)	Supports respiratory health and endurance.	Antimicrobial properties may enhance respiratory function.	Used in traditional Australian medicine system for its health benefits.	(48)
36.	*Terminalia arjuna (Arjuna)*	improve cardiovascular health and treat various heart ailments such as coronary artery disease, hypercholesterolemia, hypertension, angina pain, and ischemic cardiomyopathy	improves cardiovascular endurance and lowers systolic blood pressure.	used in India for centuries to improve cardiovascular health	(49)

Historical Context of Plant Use in Sports

The historical utilization of plants for enhancing physical performance is well-documented across various cultures. In ancient Egypt, physical games and sports were integral to social entertainment and were often depicted in tombs and temples, showcasing their cultural significance. Similarly, the Greeks used various herbs and plants to boost athletic performance during the Olympic Games, demonstrating a long-standing tradition of integrating botanical knowledge into sports (50). This historical background is crucial things for understanding the roots of modern practices.

Modern Scientific Validation of Traditional Practices

Recent research has started to validate the effectiveness of traditional plant-based practices through scientific studies. Some research has shown that certain herbal supplements can enhance recovery and performance in athletes, aligning with historical claims of their benefits (51). The integration of modern scientific methods with traditional knowledge not only provides empirical support for these practices but also promotes a balanced approach to sports enhancement that values cultural traditions(52).

The Role of Globalization in Sports Practices

Globalization has significantly influenced sports practices, often leading to the decline of traditional methods as global sports cultures dominate. However, there is a growing effort to revive and incorporate these ancient practices into modern athletic training. This revival is not just a return to the past but a strategic incorporation of effective methods that have stood the test of time. The combination of traditional and modern approaches offers athletes a diverse range of options to improve their performance(53).

Modern Use of Plant-Based Enhancements

The use of plant-based enhancements is becoming more common in modern sports. Many athletes now choose natural supplements from plants to boost endurance, strength, and recovery. This shift toward natural options is driven by a preference for safer and more sustainable alternatives, especially amid concerns about the risks of synthetic enhancers. Plants like ginseng, turmeric, and various adaptogens are examples of this trend, as they are valued for their potential to support athletic performance and recovery(52).

Conclusion

Plants have played a crucial role in enhancing athletic performance since ancient times, offering natural solutions to improve strength, endurance, and recovery. From their roots in traditional practices to their growing presence in modern sports nutrition, plant-based supplements continue to be a source of interest for athletes and researchers alike. Modern science has begun to validate many of the traditional claims about the benefits of plants, such as their anti-inflammatory, antioxidant, and adaptogenic properties, which support recovery and performance.

However, the widespread use of herbal supplements comes with challenges, including concerns about safety, quality, and the lack of strict regulatory frameworks. Athletes must navigate these issues carefully, ensuring they choose supplements backed by scientific evidence and free from banned substances.

The integration of traditional knowledge with modern research presents an opportunity to develop effective, safe, and culturally respectful solutions for sports performance enhancement. By fostering a balanced approach that values both ancient wisdom and contemporary science, we can unlock the full potential of plants as natural performance enhancers, contributing to the well-being and success of athletes in a sustainable and holistic way.

Authors Contribution

Manuscript designed by Neha Singh & Kana Ram Kumawat and written by Kana Ram Kumawat; Formatting of manuscript was done by Sanjay Saini & Anil Chahar; Manuscript was reviewed and finalized by Arvind Pareek. All authors have read the final version of the manuscript and agreed to the publication.

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Germinability in Sesame Cultivars in Response to Varying Factors

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Keywords : *Germinability, Sesame, Cultivars, Varying factors.*

Abstract :

Germinability in Sesame cultivars has been worked out in response to varying factors like moisture and salt stress, light qualities, photoperiods, temperature, pH, different soil types and phytohormones. In control, GT-10 germinated up to 81.66%, TKG-22 70%, AT-324 39.66%, JTS-8 50% and local up to 69.66%. Rubbing of seeds by abrasive paper enhanced the germination percentage. Minor and moderate moisture stresses were suitable for all cultivars. Salt stresses declined the germination potential. GA3 induced germination at 10ppm. The findings have been used to correlate germinability among different cultivars.

INTRODUCTION

Seed germination is well co.ordinated programmes which include those processes that lead to initiation of growth in the quiescent embryonic sporophyte. Seeds may germinate after harvest or do not so due to germination inhibitors or some sort of dormancy. Proper hydration encourages metabolism and oxygen availability is guaranteed. Germination starts from emergence of radicle from seed coat. The emergence of radicle depends upon the interaction of seeds with diverse factors (Sinha et al., 1991, Oomes and Elberse, 1976, Paul et al., 2008, Kumari, 2010). In the present investigation, five sesame cultivars have been selected to work out their germinability in response to varied factors. Sesame tolerates drought conditions well in growing condition as against other crops which generally fail.

MATERIALS AND METHODS

Sesame (Sesamum indicum L.) is a member of family Pedaliaceae. Seeds were procured from Bihar Agriculture University, Sabour after Mou and local cultivar from Hajipur. The cultivars are GT-10, TKG-22, AT-324, JTS-8 and Hajipur local. For germination studies, seeds were surface sterilized by treating them with 0.1% HgCl2 solution for five minutes. Further seeds were washed and germinated in sterilized Petridishes on single layer filter paper placed uniformly on a cotton wool moistened with distilled water. Three replicates each containing 25 seeds were maintained in all the experiments. Seed coat pricked by fine needle, did not induce the germination percentage. Seeds were rubbed by abrasive paper and it worked. Concentrated H_2SO_4 treatment for 5-10 minutes was done to break partial dormancy present in the seeds. Effect of moisture stress was studied by following the method of Sinha et al, (1991). Here the artificial stress was created by increasing the number of filter papers keeping the amount of water constant. To study the effect of salt

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stresses, NaCl, KCl, and $MgSO_4$ were selected. The concentrations used were 0.5 to 3.5%. Effect of varying temperature on germination was studied by keeping the Petridishes containing seeds at 4°c, 22°c, 32°c and 40°c. Light of different wavelengths was created by covering the incandescent bulbs with cellophane paper of desired colour. Effect of varying photoperiods was studied in the departmental lab at 35°c. Different pH values solutions were prepared with the help of trihydroxymethyl aminomethane and HgCl2 as well as citric acid and sodium citrate. The seeds were kept moistened with these solutions. Effect of IAA, GA3 and Cytokinin was worked out by preparing varying hormonal concentrations ranging from 10-100 ppm. In all experiments, the results obtained were compared with control. For germinability, the parameters selected were initiation period, rate of germination per day in percentage and final percentage of germination for 10 days. Seeds with 1mm radicle emerged were considered to be germinated.

RESULTS AND DISCUSSION

The seeds procured showed unhealthy seeds as were 8% each in GT-10 and TKG-22, 10% in AT-324 and 9% in JTS-8. It was 17% in local variety.

In control, GT-10 germinated up to 81.66%, other cultivars TKG-22 upto70%, AT-324 up to 39.66%, JTS-8 up to 50% and local ones up to 69.66 %.

Seeds were pricked by fine needle to enhance germinability. But it failed to enhance the germination percentage.

The Table-1 shows germination percentage in seeds rubbed by abrasive paper as 85.33% in GT-10, 69.66% in TKG-22, 60% in AT-324, 56% in JTS-8 and 70% in Local. Rubbing the seeds by abrasive paper improved the germination in AT-324, GT-10 and JTS-8.

Table -1

Seed germination by abrasive paper *in Sesamum indicum* cultivars

Cultivars	Initiation period (days)	Rate of germination per day (%)	Percentage of germination ± S.E
GT-10	04	8.53	85.33±2.02
TKG-22	04	6.96	69.66±2.02
AT-324	03	6.00	60.00±1.15
JTS-8	04	5.6	56.00±0.57
LOCAL	03	7.00	70.00±2.88

Effect of conc. H_2SO_4

Concentrated H_2SO_4 treatment for 5 – 10 minutes failed to germinate the seeds in all the cultivars.

Effects of moisture stress

Five moisture regimes were created for knowing germination potential in all the five cultivars. Moisture regimes were control, minor stress, moderate stress, high stress and highest stress. The figure-1 showed decreased germination potential in minor to maximum stress. The maximum stress reduced the germination. Moderate stress improved the germination process in AT-324. JTS -8 tolerated minor and moderate stress. Wang et al., (1995) reported that the degree of osmotic adjustment is substantially influenced by the rate at which development of water stress takes place. Oxidase and hydrolytic enzymes activity are arrested at high stress (Khadeer et al, 1987, Kumari, 2010).

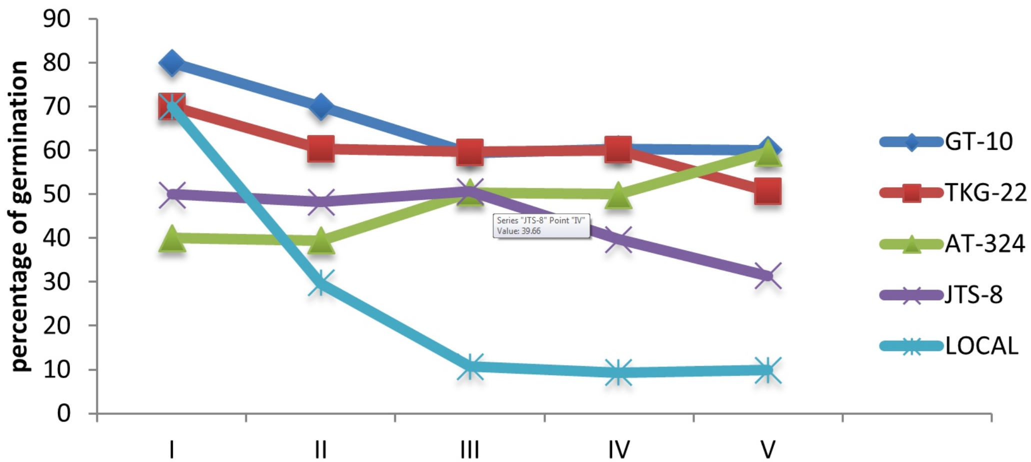

Figure-1 : Effect of moisture regimes

Effect of salt stress

For the investigation, NaCl, KCl, and MgSo4 were selected in the concentration range of 0.5 to 3.5%.

The figures-2-4 showed declined germination in response to salts selected in all cultivars and responses vary. There was increase in ascorbate peroxidase ,catalase activity and proline content due to increased salinity stress. Stewart et al., (1977) reported accumulation of free proline under chloride salinity.

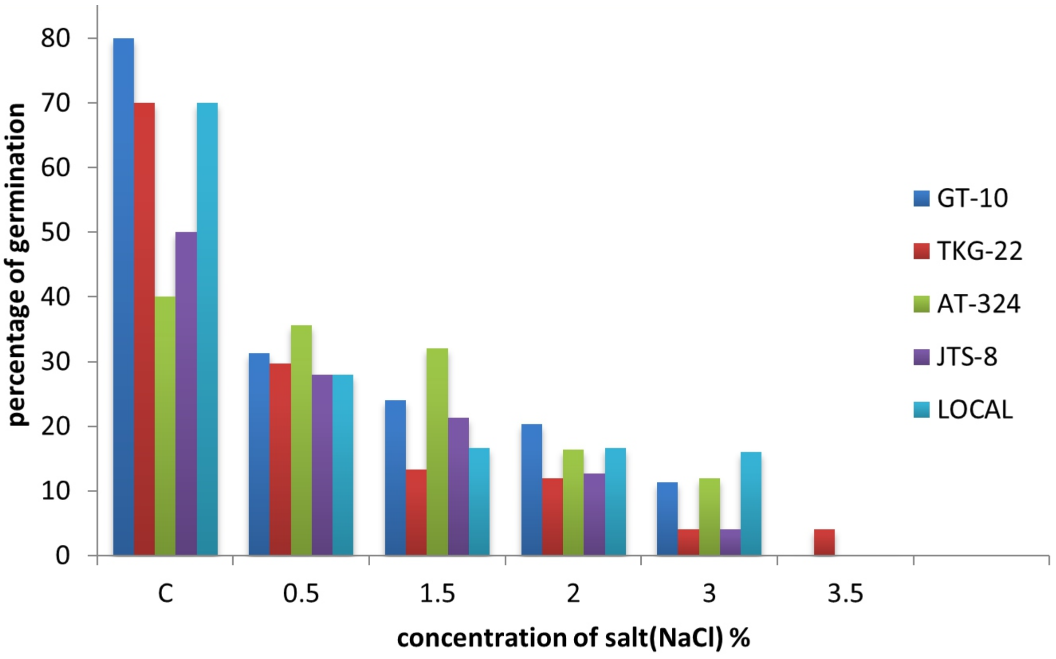

Fig 2 : Effect of salt stresses

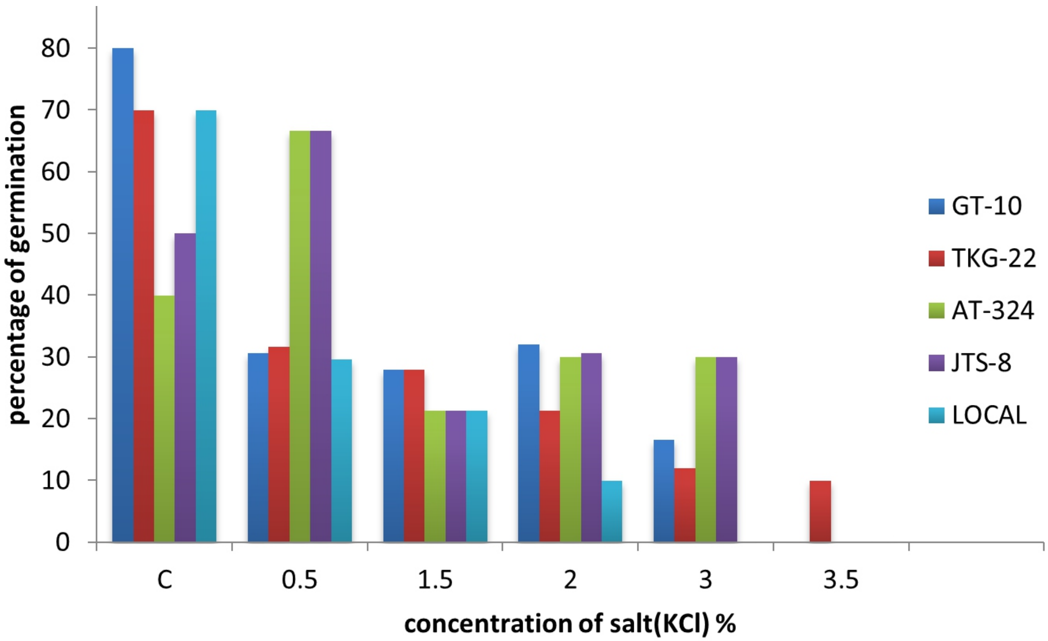

Fig 3 : Effect of salt stresses

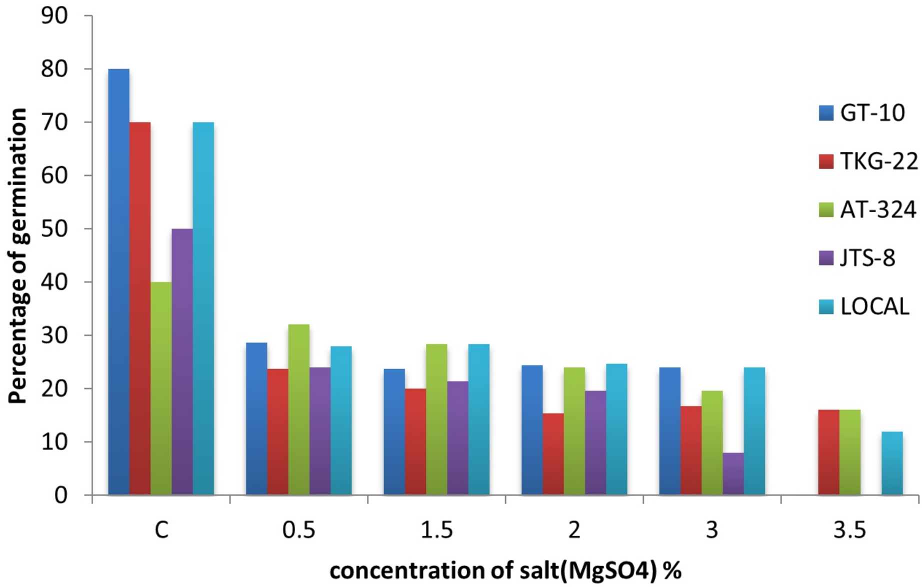

Fig 4 : Effect of Salt Stresses

Effect of pH

The effect of pH range from 6.0 to 10 on germinability of cultivars under reference has been studied and the results are presented in Fig.-5.

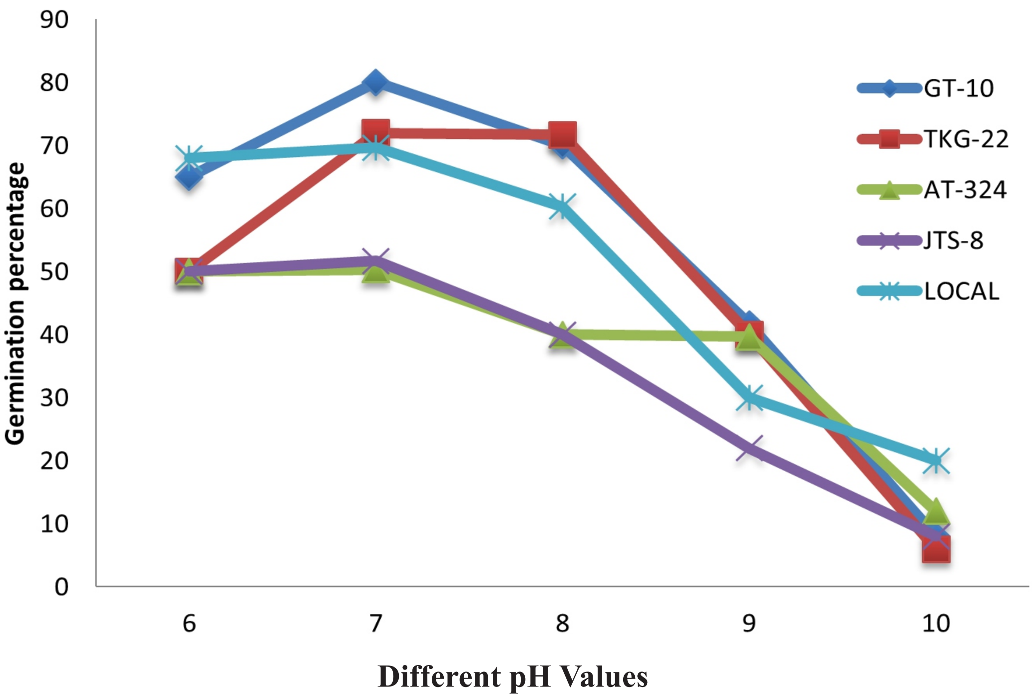

Fig 5: Effect of pH values on germination

Effect of soil types

Seeds of all five cultivars were germinated in response to loamy, sandy, clay and Gangetic alluvial soils.

Loamy and Gangetic alluvial soil were the best for seed germination. GT-10 showed germination up to 80.66-85% in both soil types.

Effect of different qualities of light

In red light, the germination percentage was 80 in GT-10, 70.66% in TKG-22 and AT-324, JTS-8 and 90% in local. Blue light stimulated the germination in local variety and it was 90%.

Effect of photoperiods

Three photoperiods were selected for scoring germination 16 hour light/ 8 hour darkness, 12 hour light/ 12 hour darkness and 8 hour light / 16 hour darkness.

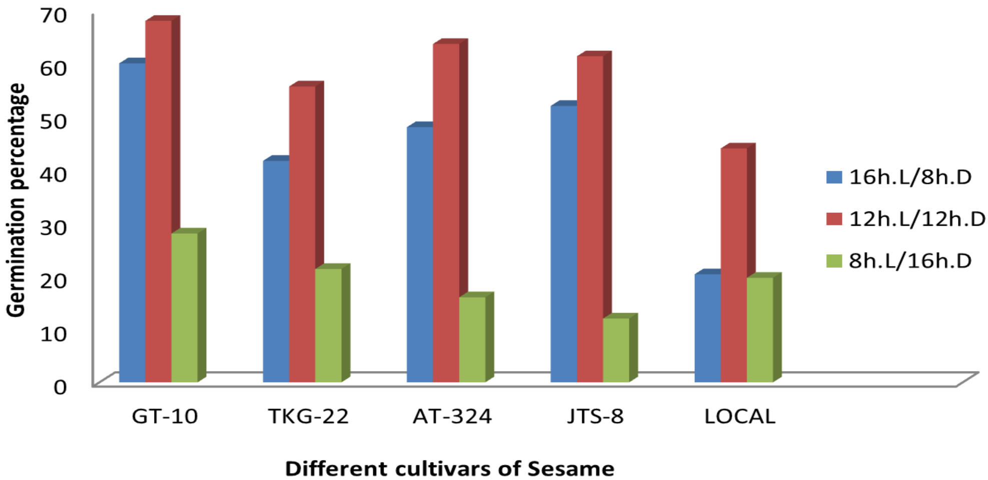

Fig 6: Effect of photoperiods on germination

In 12hL/12hD the cultivars did well (figure-6). Ahmad and Bano (2007) have reported induced germination in dormant seeds of orange fruited plant of Solanum nigrum owing to appropriate photoperiod.

Effect of temperature

At 32-33°c, GT-10 showed 80.33% germination, TKG-22 up to 60%, AT-324 up to 41.66%, JTS-8 up to 42% and local up to 28%.

Effect of IAA, GA3 and Cytokinin

All the cultivars more or less responsed negativety to different concentrations of IAA. In GA3, the cultivars showed enhanced germination at 10 ppm. Higher concentrations were inhibitory (Fig-7). Trivedi and Anupama (2010) reported that Gibberellic acid has the capacity to break the dormancy in seeds of many plants. In cytokinin also, all the cultivars responded positively at 10 ppm concentration.

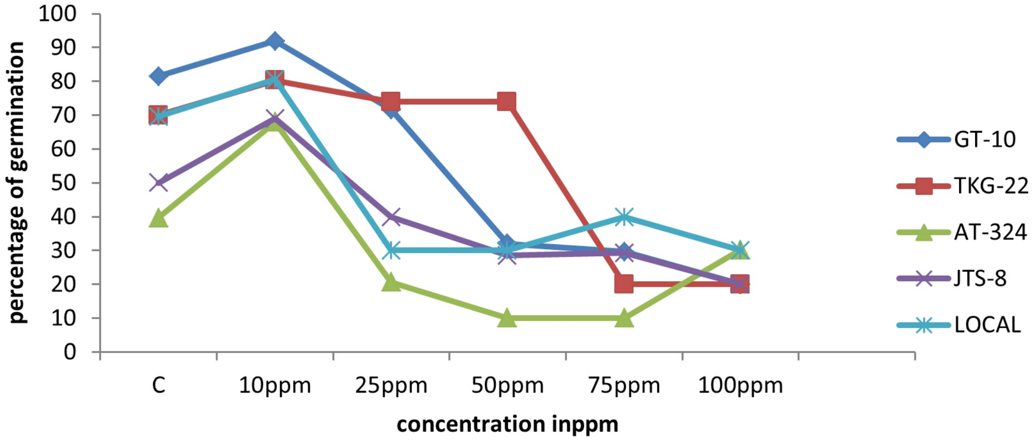

Fig 7 : Effect of GA3

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Medicinal Plants of Rajasthan : Traditional and Therapeutic approach for Wound Healing

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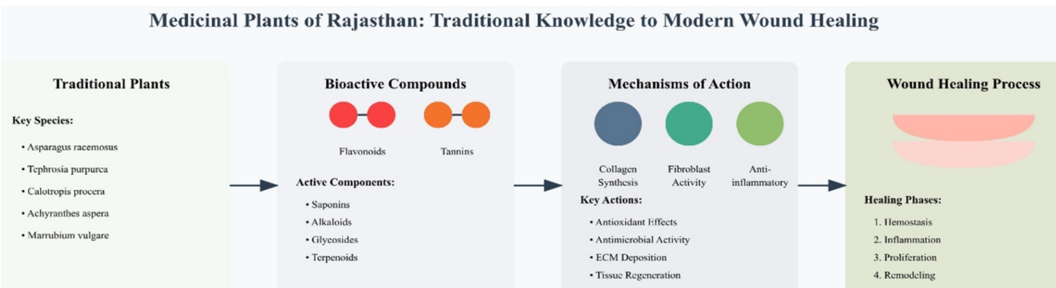
Keywords : Medicinal plants, Wound healing, Traditional approach

Abstract

The grasses and herbaceous plants of Rajasthan have garnered attention for their significant role in wound healing, attributed to their diverse phytochemical profiles, including flavonoids, tannins, and saponins. Plants such as Asparagus racemosus, Tephrosia purpurea, and Calotropis procera exhibit various therapeutic properties, including enhancing collagen synthesis, promoting fibroblast activity, and supporting extracellular matrix deposition, which are crucial for tissue repair and wound closure. Other plants like Achyranthes aspera and Marrubium vulgare demonstrate antibacterial, anti-inflammatory, and antioxidant effects that aid in infection prevention and tissue regeneration. Additionally, Quercus infectoria and Asphodelus aestivus further validate their traditional use with their antioxidant properties that promote wound healing. These findings suggest that the integration of these plants into modern wound care practices could offer viable alternatives to synthetic treatments, particularly in regions where these plants are abundant. Future research should focus on isolating and understanding the bioactive compounds involved to enhance their therapeutic efficacy in wound healing.



Introduction

Wound healing is a complex biological process that involves a series of coordinated events aimed at restoring the integrity of damaged tissue. This process is crucial not only for physical recovery but also for preventing infections and other complications that can arise from open wounds. Traditionally, wound healing has been approached through various therapeutic modalities, including the use of medicinal plants, which have been integral to many cultures, particularly in regions like Rajasthan, India. The rich biodiversity of Rajasthan has endowed its inhabitants with abundance of medicinal plants that are utilized for their wound healing properties, often based on centuries of traditional knowledge. This review aims to

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explore the traditional and therapeutic approaches to wound healing through medicinal plants found in Rajasthan, highlighting their biochemical properties and potential applications in modern medicine.

Process of Wound Healing

Wound healing is generally categorized into four overlapping phases: hemostasis, inflammation, proliferation, and remodeling. The initial phase, hemostasis, occurs immediately after injury, where blood vessels constrict and platelets aggregate to form a clot, preventing excessive blood loss. Following this, the inflammatory phase begins, characterized by the recruitment of immune cells to the wound site. This phase is essential for clearing debris and pathogens, setting the stage for tissue repair[1, 2].

The proliferation phase involves the formation of granulation tissue, where fibroblasts synthesize collagen and extracellular matrix components, providing structural support for new tissue. Angiogenesis, or the formation of new blood vessels, also occurs during this phase, ensuring an adequate supply of nutrients and oxygen to the healing tissue [3, 4]. Finally, the remodelling phase can last for months to years, during which collagen is reorganized and strengthened, ultimately restoring the skin's integrity and function[5-7].

Role of Medicinal Plants of Rajasthan in Wound Healing

Rajasthan is home to a diverse array of medicinal plants that have been traditionally used for wound healing. These plants often contain bioactive compounds that promote various stages of the healing process. For instance, the methanol extract of *Achyranthes aspera* has demonstrated significant antimicrobial activity against common wound pathogens, thereby reducing the risk of infection and promoting faster healing [8]. Similarly, *Aloe vera*, known for its soothing properties, has been shown to enhance wound healing through its anti-inflammatory and antimicrobial effects[9].

Another notable plant is *Sansevieria trifasciata*, whose hydrogel extract has been evaluated for its wound-healing activity, showing promising results in enhancing skin restoration [10]. The phytoconstituents present in these plants, such as flavonoids, terpenoids, and phenolic compounds, contribute to their therapeutic efficacy by exhibiting antioxidant and antimicrobial properties [11, 12]. Furthermore, the traditional use of these plants is often supported by scientific investigations, validating their roles in modern therapeutic applications[13, 14].

The ethnobotanical knowledge surrounding these plants is crucial for their application in wound healing. For example, *Marrubium vulgare* has been traditionally used for its wound healing properties, and recent studies have confirmed its phytochemical composition and antioxidant capabilities, which are essential for tissue repair [13]. Additionally, the use of *Ceylon cinnamon* has been reported to accelerate wound healing due to its anti-inflammatory and antimicrobial properties[15].

S. No.	Medicinal Plants (Family)	Traditional Uses	Therapeutic Approaches	Ref.(s)
1.	*Lawsonia inermis* (Henna) (Lythraceae)	Traditionally used for its antimicrobial properties and to promote wound healing.	The application of henna in ointments has shown significant wound healing activity.	[16]
2.	*Punica granatum* (Pomegranate) (Lythraceae)	Used in traditional medicine for its antioxidant and anti-inflammatory properties.	Pomegranate extracts enhance collagen synthesis and promote re-epithelialization.	[16, 17]
3.	*Commiphora myrrha* (Myrrh) (Burseraceae)	Historically utilized for its antiseptic properties in wound management.	Myrrh has been shown to facilitate wound healing through its anti-inflammatory effects.	[16, 18]
4.	*Curcuma longa* (Turmeric) (Zingiberaceae)	Widely recognized in traditional medicine for its anti-inflammatory and healing properties.	Curcumin, the active compound in turmeric, accelerates wound healing and tissue regeneration.	[19, 20]
5.	*Tridax procumbens* (Asteraceae)	Known for its traditional use in treating wounds and skin infections.	Exhibits significant wound healing properties due to its phytochemical composition.	[21, 22]
6.	*Ocimum sanctum* (Holy Basil) (Lamiaceae)	Used in traditional remedies for its healing and anti-inflammatory properties.	Enhances wound contraction and epithelialization, promoting faster healing.	[23-25]
7.	*Morinda tinctoria* (Rubiaceae)	Traditionally used for its wound healing properties in various cultures.	Aqueous extracts have shown efficacy in promoting wound healing through various mechanisms.	[26, 27]
8.	*Desmodium gyrans* (Fabaceae)	Known for its traditional use in treating wounds and enhancing healing.	Extracts have demonstrated significant wound healing activity in experimental models.	[20]

9.	*Mimusops elengi* (Sapotaceae)	Traditionally used for its wound healing properties in various cultures.	Methanolic extracts have shown potential in enhancing wound healing through tensile strength.	[28]
10.	*Ficus* sp. (Moraceae)	Traditionally utilized for their wound healing and anti-inflammatory properties.	Exhibits antioxidant and anti-inflammatory effects beneficial for wound management.	[29]
11.	*Chenopodium album* (Chenopodiaceae)	Used in traditional medicine for urinary troubles and wound healing.	Exhibits properties that inhibit crystallization and promote healing.	[30]
12.	*Malva sylvestris* (Malvaceae)	Traditionally used for its soothing and healing properties on wounds.	Extracts have demonstrated significant effects on various phases of wound healing.	[28, 31]
13.	*Curcuma domestica* (Zingiberaceae)	Used traditionally for its healing properties in wounds and skin conditions.	Contains curcuminoids that promote wound healing and tissue regeneration.	[19, 20]
14.	*Aloe vera* (Asphodelaceae)	Widely recognized for its soothing and healing properties on wounds.	Promotes wound healing through its anti-inflammatory and moisturizing effects.	[32]
15.	*Bryophyllum pinnatum* (Crassulaceae)	Used in traditional medicine for its wound healing properties.	Demonstrates significant effects on wound healing through various biological pathways.	[19]
16.	*Elephantopus scaber* (Asteraceae)	Traditionally utilized for its healing properties in skin conditions.	Exhibits wound healing activity through its anti-inflammatory and antioxidant properties.	[19]
17.	*Plantago major* (Plantaginaceae)	Known for its traditional use in treating wounds and skin irritations.	Demonstrates significant wound healing properties through its phytochemical composition.	[31]

The integration of traditional knowledge with modern pharmacological research can lead to the development of effective wound healing therapies. The exploration of plant-based compounds for their wound healing potential is gaining traction, as they often present fewer side effects compared to synthetic alternatives. Moreover, the use of phytoconstituents in innovative wound dressing materials is an emerging area of research, aiming to enhance healing outcomes while minimizing complications associated with conventional treatments[33, 34].

Table 2: Wound Healing Properties of Herbs in Rajasthan

S. No.	Medicinal Plant	Family	Active Compounds	Mechanism of Action	Ref.(s)
1.	*Asparagus racemosus*	Liliaceae	Saponins, alkaloids	Enhances collagen synthesis and fibroblast activity, increases tensile strength of skin	[35]
2.	*Tephrosia purpurea*	Fabaceae	Flavonoids, tannins	Exhibits antioxidant activity and promotes fibroblast proliferation	[36]
3.	*Calotropis procera*	Asclepiadaceae	Cardiac glycosides, flavonoids	Stimulates fibroblast proliferation and extracellular matrix deposition	[37]
4.	*Achyranthes aspera*	Amaranthaceae	Saponins, alkaloids	Promotes wound healing through antibacterial and anti-inflammatory effects	[8]
5.	*Marrubium vulgare*	Lamiaceae	Diterpenes, flavonoids	Enhances antioxidant activity and promotes tissue repair	[13]
6.	*Quercus infectoria*	Fagaceae	Tannins, flavonoids	Acts as a free radical scavenger, promoting healing through antioxidant mechanisms	[38]
7.	*Asphodelus aestivus*	Asphodelaceae	Saponins, flavonoids	Validates traditional use in wound treatment through enhanced healing properties	[39]
8.	*Eclipta alba*	Asteraceae	Coumarins, flavonoids	Promotes re-epithelialization and collagen synthesis	[40]

The medicinal plants of Rajasthan offer a rich resource for developing effective wound healing therapies. Their traditional uses, supported by scientific evidence, underscore the importance of integrating ethnobotanical knowledge with modern pharmacological research. As the field of wound healing continues to evolve, these plants may play a pivotal role in addressing the challenges associated with wound management and recovery.

Discussion

The grasses and herbaceous plants of Rajasthan have been recognized for their significant roles in wound healing, attributed to their diverse phytochemical profiles. The active compounds found in these plants, such as flavonoids, tannins, and saponins, contribute to their therapeutic efficacy by promoting various mechanisms involved in the wound healing process. For instance, *Asparagus racemosus* has been shown to enhance collagen synthesis and fibroblast activity, which are crucial for the structural integrity of healing tissues [35]. Similarly, *Tephrosia purpurea* exhibits antioxidant properties that support wound healing by scavenging free radicals and promoting fibroblast proliferation[36].

Moreover, *Calotropis procera* has demonstrated the ability to stimulate fibroblast proliferation and extracellular matrix deposition, which are essential for effective wound closure [37]. The traditional use of *Achyranthes aspera* in wound healing is supported by its antibacterial and anti-inflammatory properties, which help prevent infection and promote healing [8]. The presence of potent antioxidants in *Marrubium vulgare* further enhances its role in tissue repair[13].

In addition, *Quercus infectoria* and *Asphodelus aestivus* validate their traditional uses through their antioxidant and healing-promoting effects[38, 39].

The integration of these medicinal plants into modern wound care practices could provide effective alternatives to synthetic treatments, particularly in regions where these plants are readily available. Future research should focus on isolating specific bioactive compounds and understanding their mechanisms of action to enhance the therapeutic potential of these plants in wound healing.

Conclusion

The medicinal plants of Rajasthan play a crucial role in wound healing, with their diverse phytochemical compositions contributing to antimicrobial, anti-inflammatory, and antioxidant effects. The presence of bioactive compounds such as flavonoids, tannins, saponins, and alkaloids enables these plants to promote collagen synthesis, enhance fibroblast proliferation, and accelerate tissue regeneration. Traditional knowledge, supported by modern scientific research, underscores the potential of plants like *Asparagus racemosus*, *Tephrosia purpurea*, *Calotropis procera*, and *Achyranthes aspera* in facilitating different phases of wound healing.

The integration of these medicinal plants into contemporary wound care practices offers a promising alternative to synthetic treatments, particularly in resource-limited settings. Further pharmacological investigations and clinical studies are necessary to isolate and characterize the active compounds responsible for their therapeutic effects. Additionally, the development of plant-based formulations, such as wound dressings and topical applications, can enhance their efficacy and commercial viability. By bridging traditional ethnobotanical knowledge with modern medical advancements, the therapeutic potential of Rajasthan's flora can be fully realized, contributing to innovative and sustainable wound healing solutions.

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Microalgal Beta Carotene : Source of Nutrition for Human Being

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Keywords : *Beta-carotene, Microalgae, Human health, Nutrition.*

Abstract

Beta-carotene, a crucial carotenoid, plays a vital nutritional role in human health as a precursor to vitamin A and a potent antioxidant. Various microalgal, particularly Dunaliella salina, Arthrospira platensis, and Chlorella vulgaris, are among the richest natural sources of β-carotene. These microalgae can accumulate high levels of β-carotene under stress conditions such as high salinity, intense light, and nutrient limitation. Its health benefits extend beyond vitamin A production, including enhanced immune function, improved vision, protection against oxidative stress, and reduced risk of chronic diseases such as cardiovascular disorders and cancer. The natural β-carotene from microalgae represents a sustainable and eco-friendly alternative to synthetic production, highlighting the potential for large-scale cultivation and commercial application in nutraceuticals and functional foods. This review explores the nutritional significance of microalgal-derived β-carotene, its bioavailability, health benefits, and prospects for human health.

Introduction

β-carotene ($C_{40}H_{56}$) is a fat-soluble carotenoid and a provitamin A compound that the human body converts into retinol (vitamin A). β-carotene exists in trans and cis configurations, with the all-trans form being the most bioavailable and biologically active. Its conjugated double-bond system is responsible for its potent antioxidant properties and vibrant orange-red color in nature (Ötles & Çagindi, 2007; Johnson & Russell, 2010). It is widely found in plant-based sources such as carrots, sweet potatoes, spinach, and microalgae (e.g., Dunaliella salina, Arthrospira platensis). Its antioxidant activity helps to neutralize free radicals, reducing cellular damage and inflammation. The importance of β-carotene extends beyond its nutritional value, contributing to skin protection, immune modulation, and lowering the risk of age-related diseases. Beta Carotene was considered an appropriate chemo-preventive agent to be tested in supplement trials since it was approved for human consumption by the U.S. Food and Drug Administration (Dufossé et al., 2005; Monte et al., 2020).

Benefits to Human Health

The main carotenoids involved in human health are β-carotene, alpha-carotene, lycopene, lutein, beta-cryptoxanthin, and zeaxanthin, which can be found in blood plasma. Except for zeaxanthin, these compounds are easily obtained from food, and β-carotene is the most abundant in the diet (Silva & Mercadante, 2002; Sacco et al., 2003; Rodriguez-Amaya & Kimura, 2004). Fifty carotenoids have

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provitamin A activity, and the most important precursor is β-carotene (Olson, 1989). The other important precursors are α-carotene and β-cryptoxanthin, each have at least one ionone ring at the end of the isoprenoid structure (Meléndez-Martínez et al., 2004). In addition to their roles as vitamin A precursors, other health benefits have been suggested for carotenoids, such as the prevention of certain cancers, protection of gastric mucosa against ulcers, capacity to prevent photosensitization in certain skin diseases, increase of immune response to infection and anti-aging properties (Carvalho et al., 2013). Carotenoids can also be converted into retinol (provitamin A activity). Furthermore, in addition to their role as the macular pigments of the eye, these substances have antioxidant activity. They are involved in several cellular processes, such as modulating inflammatory response, protecting against cancer, and preventing cardiovascular diseases and cataracts. The antioxidant capacity of carotenoids is most likely responsible for their ability to protect against the detrimental health effects of vitamin A deficiency; its antioxidant properties help protect cellular structures from oxidative stress, reducing the risk of chronic diseases such as cancer and cardiovascular conditions (García-Sánchez et al., 2020). Subclinical vitamin A deficiency, in which visible signs of xerophthalmia are absent, intensifies the severity of certain illnesses, such as diarrhoea and other infectious diseases, eventually resulting in immunodeficiency of exclusively nutritional origin (Sumarno, 1994). As a provitamin A compound, β-carotene is critical in maintaining vision, immune function, and skin health (Liu & Yildiz, 2018). Given that the human body converts β-carotene into vitamin A as needed, it represents a safer option than direct vitamin A supplements, minimizing toxicity risks associated with excessive intake (Mayne, 1996; Alashry & Morsy, 2021).

Microalgal Source for Beta Carotene

Microalgae are increasingly recognized as potential sources of β-carotene, a vital carotenoid with several health benefits, including functioning as a precursor to vitamin A and exhibiting antioxidant properties. They offer a natural alternative to synthetic sources of β-carotene, which are often criticized for lower bioavailability and adverse health effects compared to natural forms. (Henríquez et al., 2016; Khanum et al., 2020; Marinoa et al., 2020). Microalgae such as Dunaliella salina, Spirulina, and Chlorella, are particularly highlighted for their efficiency in β-carotene production when optimized growth conditions are applied (Del Campo et al., 2007; Chen et al., 2017). Other microalgae such as Haematococcus pluvialis, Scenedesmus obliquus, Nannochloropsis oculate, and Isochrysis galbana produce beta carotene; their applications are mentioned in Tables 1 and 2.

Dunaliella salina is the most prominent source of β-carotene among microalgae. It accumulates β-carotene content up to 14% of its dry weight, especially under stress conditions such as high salinity, nutrient deficiency, and excessive light intensity (Borowitzka, 1990; Shaker et al., 2017). This microalga has been cultivated commercially for its high β-carotene yield, which is utilized in dietary supplements and food coloring agents due to its coloring properties (de Melo Santana et al., 2022).

Arthrospira platensis, commonly known as Spirulina, is another well-known microalga that is rich in β-carotene, along with other beneficial carotenoids like lutein and zeaxanthin (Wang et al., 2022). Spirulina is often promoted as a "superfood" because of its high nutrient content and health benefits. It is known for its antioxidant properties and ability to strengthen the immune system (Molino et al., 2018) Spirulina is grown in carefully controlled environments, which helps improve the yield and purity of the β-carotene extracted from it, making it more effective when used in supplements.

Chlorella, particularly Chlorella vulgaris, is also noted for its nutritional contribution, containing significant amounts of β-carotene and being a complete source of protein and essential amino acids (Molino et al., 2018). It is often consumed as a dietary supplement or health food due to its capacity to support detoxification and enhance energy levels. The bioavailability of β-carotene from Chlorella is considered favorable compared to other sources due to its lipid matrix and cell wall structure, which can facilitate absorption in the human body (Jung et al., 2016).

Microalgal Species and Beta-Carotene Production

An overview of key microalgal species cultivated on a large scale for their β-carotene content, their primary production regions, and leading manufacturing companies is mentioned in Table 1.Table 1: β-carotene content from algae with production area worldwide.

Table 1 : β-carotene content from algae with production area worldwide.

Algal Species	Primary Production Areas	Company Name	β-carotene Content (%)	Ref.(s)
Dunaliella salina	Israel, USA, Australia	Betatene Ltd	14%	(Raja et al., 2007; Acacio-Chirino et al., 2013; Vo & Tran, 2014)
Haematococcus pluvialis	USA, Thailand	Algatechnologies	3–5%	(Grewe & Griehl, 2012)
Chlorella vulgaris	Asia (Taiwan, Japan), USA	Sun Chlorella	1–2%	(Geetha et al., 2010; Damergi et al., 2017)
Scenedesmus obliquus	China, Europe	PhycoBiologics	1.5%	(do Nascimento et al., 2021)
Nannochloropsis oculata	USA, Europe	Algenol	1.5%	(Faé Neto et al., 2018; MU et al., 2019)

Nutritional Role of Beta-Carotene

β-carotene's conversion to vitamin A is essential for maintaining healthy skin, vision, and immune function (Kiani, 2007). Numerous studies have elucidated the relationship between dietary β-carotene and reduced risk of chronic diseases, including cardiovascular diseases and certain cancers —(Kaulmann & Bohn, 2014; Bohn, 2017). For instance, systematic reviews have associated long-term β-carotene supplementation with protective effects against oxidative stress-related diseases (Druesne.Pecollo et al., 2010; Additives & Food, 2012; Kaulmann & Bohn, 2014; Corbi et al., 2022). Sources of beta carotene content derived from different microalgae, their nutritional value, and their application are described in Table 2.

Table 2 : Microalgal sources of β-carotene, their nutritional values, and applications.

Microalgal Source	β-carotene Content (% Dry Weight)	Nutritional Claims	Main Applications	Ref.(s)
Dunaliella salina	Up to 14%	Antioxidant, immune enhancement, skin health	Dietary supplements, food additives	(Alishahi et al., 2015; Sanderson, 2018; Roy et al., 2021)
Spirulina platensis	2–10%	Antioxidant boosts energy, supports immune function	Nutritional supplements, food product	(Finamore et al., 2017; Seyidoglu et al., 2017)
Chlorella vulgaris	1–5%	Detoxification, energy enhancement, antioxidant properties	Dietary supplements, aquaculture	(Gao & Tam, 2011; Sikiru et al., 2019)
Nannochloropsis oculata	1–3%	Supports heart health, potential anti-inflammatory effects	Aquaculture feed, health products	(du Preez et al., 2021; Gallego et al., 2022)
Isochrysis galbana	1–2%	Improves growth, immune function, and nutritional value in larvae	Aquaculture feed	(Guedes & Malcata, 2012)

Nutritional Value of Beta-Carotene in Human Health

The nutritional value of β-carotene underscores its importance in dietary supplementation and animal feed systems. Its role in enhancing immunity, promoting better vision, and protecting cellular structures against oxidative damage positions β-carotene as an essential human nutrient (Table 3). Furthermore, the sustainability of microbial sources makes them appealing in addressing the growing demand for natural supplements amid increasing ecological concerns regarding traditional agriculture (Mayne, 1996; Burri, 1997; Biesalski & Obermueller-Jevic, 2001)

Table 3 : β-carotene Nutritional Value and Health Benefits.

Nutritional Aspect	Description	Health Benefits	Recommended Intake	Bioavailability Factors	Ref.(s)
Vitamin A Precursor	β-carotene is converted to vitamin A (retinol) in the body	Support vision, Maintain immune function, Promote cell growth and differentiation, Support reproductive health	No specific RDA for β-carotene; Vitamin A RDA: 900 μg RAE for men, 700 μg RAE for women	Conversion rate: 12 μg β-carotene = 1 μg retinol, Fat-soluble: absorption enhanced with dietary fat	(Grune et al., 2010; Haskell, 2012).
Antioxidant Properties	Neutralizes free radicals and reduces oxidative stress	Protect cells from oxidative damage, May reduce inflammation - Potential to slow aging processes, Support cardiovascular health	3-6 mg/day suggested for antioxidant benefits	Cooking increases bioavailability, Chopping/processing improves absorption, Food matrix affects release	(Stahl & Sies, 2003; Fiedor & Burda, 2014)
Eye Health	Lutein and zeaxanthin (related carotenoids) protect the retina	Protect against age related macular degeneration, Reduce risk of cataracts, Improve night vision, Filter harmful blue light	10-15 mg/day may be beneficial for eye health	Smoking reduces serum levels, Alcohol consumption can impair absorption, Higher bioavailability from supplements vs. food	(Group, 2007; Bernstein et al., 2016)
Skin Protection	Acts as internal sunscreen and skin health promoter	Provide modest photoprotection (SPF ~4), Reduce skin erythema from UV	15-30 mg/day for skin photoprotection	Takes 8-10 weeks to build up protective levels, Individual variation in absorption and utilization	(Darvin et al., 2011; Stahl & Sies, 2012)
		exposure, Promote wound healing, Support skin cell renewal			

Immune System Support	Enhances immune response and communication	Support T-cell mediated immunity, Enhance natural killer cell activity, Modulate inflammatory response, Support mucosal barrier integrity	6-15 mg/day for immune support	Nutritional status affects conversion efficiency, Genetic factors influence absorption	(Hughes, 2001; Chew & Park, 2004)
Cardiovascular Health	Reduces oxidation of LDL cholesterol	Support endothelial function, Reduce atherosclerosis progression, Support healthy blood pressure-Improve lipid profiles	5-10 mg/day may support cardiovascular health	Gut microbiome composition affects absorption, Individual variation in carotenoid metabolism	(Kritchevsky, 1999; Voutilainen et al., 2006)
Cancer Prevention	Potential chemopreventive properties (still being researched)	Reduce the risk of certain cancers, Support DNA repair mechanisms, Induce apoptosis in damaged cells, Inhibit cancer cell proliferation	No specific recommendation; balanced diet approach preferred	Smoking reduces protective effects, Alcohol consumption may impair utilization	(Blumberg, 1994; Tanaka et al., 2012; Clinton et al., 2020)
Cognitive Function	Neuroprotective effects through antioxidant mechanisms	Support memory and cognitive processing, Reduce age related cognitive decline, Protect neurons from oxidative damage,	No established recommendation; research ongoing	Blood-brain barrier limits direct access, Age affects absorption and utilization efficiency	(Johnson, 2012; Rafnsson et al., 2013)

RDA : Recommended Dietary Allowances; RAE : Retinol Activity Equivalents

Production Conditions and Optimizations

Various cultivation conditions, including light intensity, temperature, and nutrient availability, influence the accumulation of β-carotene in microalgae (Çelekli et al., 2009; Morowvat & Ghasemi, 2016; Pourkarimi et al., 2020). It has been shown that *Dunaliella salina* can produce up to 10% β-carotene by weight when exposed to nutrient stress and high-light conditions(Morowvat & Ghasemi, 2016; Capa-Robles et al., 2021) Advances in cultivation techniques, such as mixotrophic growth strategies, are being developed to maximize yield and enhance the metabolic pathways responsible for β-carotene biosynthesis ""(Zhou et al., 2018; OConnor et al., 2022).

Global Implications and Market Potential

As consumer awareness of the health benefits of natural products increases, the demand for microalgal-derived β-carotene is projected to rise significantly. The commercial interest in microalgae as a source of functional ingredients has spurred investments and research into biotechnological methods for enhancing production efficiency and scalability (Ford & Choi, 2013; Zhou et al., 2018). Companies focused on microalgal cultivation are tapping into markets for dietary supplements, food fortification, and functional foods, showcasing the economic viability of this sector (Vieira et al., 2020; Damessa, 2021).

Challenges in Microalgal Production

Despite the promising benefits, several challenges hinder large-scale microalgal cultivation for β-carotene production, such as high operational costs, competition with terrestrial crops, and technical barriers in harvesting and processing (MU et al., 2019; Ahmad et al., 2022). Continuous research and development are imperative to overcome these challenges and establish a robust framework for microalgal β-carotene commercialization(Rumin et al., 2020).

Conclusion

Microalgae have emerged as an important source of β-carotene due to their bioavailability and health-promoting properties. Studies confirm substantial health benefits linked with dietary intake of β-carotene, especially regarding its antioxidant effects and role in preventing chronic diseases. Continued investment in biotechnological advancements and optimized cultivation practices will be crucial for scaling production to meet increasing consumer demands for natural health products derived from microalgae. Additionally, the production of β-carotene from microalgae is more sustainable than traditional agriculture, as it requires less land & freshwater and has a lower carbon footprint. This has led to increasing interest from researchers and industries in optimizing the cultivation, extraction, and processing techniques to maximize yield and minimize production costs. Advances in genetic engineering in microalgae, such as enhancing carotenoid biosynthesis pathways, are needed to be continuously explored to improve β-carotene production efficiency further.

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Pathogenic fungal interactions of Zygomycetes in humans : A Review

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Keywords : *Biological, Clinical resistance, Human infections, Mucor, Zygomycetes.*

Abstract

Fungal infections in humans with weak immunity and compromised health conditions are of global medical concern. The growing population worldwide with advancements in medical procedures and technologies significantly add to the susceptibility and severity of fungal infections in humans. Zygomycetes, a class of fungi, include various genera causing fungal infections such as Mucor, Rhizopus, and Absidia, threaten human population in the environment. Ecology and biology related to zygomycosis infections have been studied and highlighted in this study. Additionally, this review enlightens the clinical and biological approaches related to plants. The medical spectrum of zygomycetes has expanded dramatically over the past decades and has resulted in resistance to clinical approaches as well. Antibiotic resistance related to life-threatening fungal infections, specifically class zygomycetes, is a global concern at present. The review attempts to highlight the cause, treatment, and resistance concerned with zygomycetes and encourage future research related to biological agents and resources.

Introduction

A pathogen can be defined as any organism causing disease or infection to its host. Their existence and diversity can be categorized into unicellular, multicellular, or prokaryotes to eukaryotic organisms. Further, all living organisms including plants, animals, and humans are affected by these pathogens comprising fungi, bacteria, viruses, and nematodes. Pathogenic fungi are known to interact with plants through a series of steps. These mainly include adhesion to the host surface, infection structures, penetration, and colonizing, within the host. Additionally, some fungi produce metabolites that are toxic to the plants. These antagonistic relationships can reduce plant growth, crop yield, and cause ecological disruptions and diseases (Li et al., 2022).

Over the past 20 years, human fungal diseases have grown in significance, paradoxically because the success of modern medical practice has allowed for the survival of immunocompromised patients. These patients are particularly vulnerable to infections from opportunistic pathogens, including zygomycetes, Aspergillus, and Candida species (Van and Magee, 2001).Globally, serious fungal infections affect over 300 million people, invasive fungal infections have an annual incidence of 6.5 million cases, resulting in about 3.8 million deaths (Seagle et al., 2021). COVID-19 increases the risk of acquiring fungal infections due to its impact on the immune

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system and treatments like steroids. Common fungal infections reported in COVID-19 patients include aspergillosis, candidiasis, and mucormycosis (Singh et al., 2021). Fungal infections have become serious due to delays in detection and treatment. A primary reason for the increase in fungal infections is the development of resistance to existing antifungal drugs. Rapid and sensitive detection methods for pathogens are not always available (Arastehfar et al., 2020). The growing number of individuals with weakened immune systems increases the risk of invasive fungal infections, especially mucormycosis and other infections. This research article highlights the rise in zygomycetes human fungal infections and associated drug resistance which poses a significant public health threat and improved antimicrobial stewardship, better diagnostic practices, and increased research into new antifungal agents.

Zygomycetes

Zygomycetes belonging to the phylum Zygomycota include mainly two orders of medical interest, the Entomophthorales and the Mucorales. (Dannaoui and Garcia-Hermoso, 2007) These groups of fungi are characterized based on their ability to reproduce sexually through zygospores, asexually through sporangia, lack multicellular sporocarps, and produce coenocytic hyphae. (Spatafora et al., 2016) Zygomycetes fungi are ubiquitous, and widely found on organic substrates, including bread, decaying plant parts (fruits, vegetable matter, and crop debris), soils, and animal excrement. The optimum environmental factors for the growth and sporulation of zygomycetes fungi on these substrates are 27° C temperature and high humidity. (Richardson, 2009).

Zygomycetes, distant lineages of Ascomycetes and Basidiomycetes are known to have originated during the early fungal evolutionary process. However, some zygomycetes such as Phycomyces blakesleeanus and Mucor circinelloides, use light-receiving proteins that resemble white collar-1 and white collar-2 (photoreceptor and zinc-finger protein), which were initially discovered in the ascomycete Neurospora crassa. (Grimaldi et al., 2006) The majority of Zygomycetes are saprobes, decomposing organic material, while some are parasitic, on insects and plants. They contribute to ecosystem nutrient cycling and have commercial importance in various industries, including food production and pharmaceuticals. (Muszewska et al., 2014).

Fungal infections caused by Zygomycetes in humans are commonly known as Zygomycosis (Mucormycosis). It was first described by Platauf (1885) in the research entitled Mycosis Mucorina. Platauf observed Absidia corymbifera caused this disseminated disease in a cancer patient. Initially lacking appropriate morphological and molecular identification, the infection was classified as "mucormycosis," or "Mucor infection," in the vast majority of all recorded cases. (Patel and Davidson, 2007) Mucormycosis infections are primarily caused by fungi (Rhizopus, Mucor, Rhizomucor, Mycocladus, Cunninghamella, Absidia, and Lichtheimia) from the order Mucorales and Entomophthorales. This includes Basidiobolus and Conidiobolus species that produce subcutaneous and mucocutaneous mycoses. These infections often exhibit high mortality rates, particularly with diabetes, hematological malignancies, or those undergoing immunosuppressive therapies. Moreover, these fungi are notably resistant to several antifungal drugs, complicating clinical management (Muszewska et al., 2014; Ribes et al., 2000). Current trends indicate that the increase of COVID-19-associated mucormycosis is more common in people with pre-existing diabetes, and in people taking systemic corticosteroids, and is being observed in both COVID-19 patients, and those recovering from the disease (Singh et al., 2021).

Zygopathogens

Zygomycosis infection is a rare but life-threatening fungal infection. The Mucorales and Entomophthorales are two groups of Zygomycetes that cause human disease (Table-1, Figure-1). The infection can occur through direct contact with contaminated environments or spore inhalation. Because of their aggressive growth rates and capacity to create blood clots, these fungi cause tissue ischemia and necrosis once they have established themselves in blood arteries. Zygomycosis can manifest in several forms such as rhinocerebral, pulmonary, cutaneous, and gastrointestinal mucormycosis (Bhandari et al., 2020; Gonzalez et al., 2002). The clinical management of zygomycosis involves a combination of early diagnosis, surgical intervention, antifungal therapy, and adjunctive therapies. Many cases of zygomycosis have described the use of steroids or antibiotics as additional risk factors.

Mucorales

This order is the core group of zygomycetes, including 13 families with the largest number of species that reproduce asexually by the formation of non-motile spores in a sporangium. This is the most clinically significant order, where the main infection agents include Absidia, Apophysomyces, Cokeromyces, Cunninghamella, Lichtheimia, Mucor, Saksenaea, and Rhizopus. The largest genus in Mucorales is Mucor itself, and it includes many species. Rhizopus oryzae is the most common species causing mucormycosis in approximately 70% of cases and has been identified in Africa, America, Egypt, Germany, India, Iraq, New Guinea, Taiwan, Turkey, and the United States (Grimaldi et al., 2006). Rhizopus spp. cause human disease, particularly in diabetic and immunocompromised patients. The genus Mucor belongs to the family Mucoraceae, is filamentous fungus comprising approximately 40 to 50 recognized species like Mucor amphibiorum, Mucor circinelloides, Mucor hiemalis, Mucor indicus, Mucor racemosus, and Mucor ramosissimus (Hoog et al., 2000; Larone, 1994).

Entomophthorales

This fungal order was previously classified as Zygomycetes. A new subdivision, Entomophthoromycotina, was found causing human infections, primarily producing chronic subcutaneous and mucocutaneous mycoses Most species of this order are pathogens of insects and some are saprotrophic species that contribute to nutrient cycling in ecosystems. Conidiobolus coronatus is known to cause chronic rhinofacial disease in immunocompromised. Basidiobolus ranarum tends to infect subcutaneous tissues and can lead to intestinal infections. The Entomophthorales represent a significant group of fungi with ecological importance as insect pathogens and potential implications for human health, highlighting the need for ongoing research in this area (Mendoza et al., 2015; Vilela and Mendoza, 2018).

Table 1: Morphological description of different Zygopathogens

Pathogen	Colony morphology	Sporangiophore and Sporangium	Apophysis and Columella	Rhizoid
Absidia (*Lichtheimia*)	woolly to cottony at first and becoming an olive-grey colony with age	globose or oval sporangiophore and pear-shaped, hyaline sporangium when young, light green when old	Apophyses are well-developed with funnel-shaped base, the columella is conical-shaped	Present at the swollen areas of the stolon
Apophysomyces	fluffy and white initially, turning brownish-grey with age	Erect unbranched, curved, slightly tapering towards the apex and sporangium small pyriform in shape, hyaline	Funnel or bell-shaped apophyses, hemispherical columella	Rhizoids are thin-walled, sub-hyaline, and unbranched.
Cokeromyces	Dimorphic, yeast-like texture, calcifluor white pasty colony	Hyaline, smooth-walled, broad sporangiophores, sporangium are globose or elongate	Absent	Absent
Cunninghamella	white at first, but becoming dark grey and powdery with spore development	straight, with verticillate or solitary branches, Vesicles are sub globose to pyriform or ellipsoidal or short-echinulate	Columella and apophysis are absent	Some species form rhizoids
Mortierella	white to greyish-white, downy, with a broadly zonate or lobed (rosette-like) surface appearance	Erect, single-celled, short-cylindrical, branched at the tip, Sporangia with acrotonous (terminal) branches	Columellae and apophyses are generally lacking	Absent
Mucor	cottony to fluffy, white to yellow, becoming dark grey, with age	Erect, hyaline, simple or branched, grey or brownish, globose to ellipsoidal, multi-	Columella large and typically elongated and without	Absent
		spored sporangia	apophyses	

Rhizomucor	gray to yellowish brown color	Branched, brown, round to ellipsoidal	Columella spherical to pyriform in shape without apophysis	Stolon and poorly developed rhizoids
Rhizopus	First white becomes grey or yellowish brown with sporulation.	globose to ovoid, one-celled, hyaline to brown, and striate in many species	apophysate, columellate, often collapses to form an umbrella-like structure.	Stolons and pigmented rhizoids are present
Saksenaea	white with no reverse pigment	small, oblong, 1-2 x 3-4 µm, and are discharged through the neck	Columellae are prominent and dome-shaped	darkly pigmented rhizoids
Syncephalast rum	cottony to fluffy, white to light gray	Erect, stolon-like, and often branched, finger-shaped, thin-walled	Columella hemispherical or discoid	Adventitiou s rhizoids present
References: (Benny et al., 2001; Sciortino Jr, 2017; Walsh et al., 2018; Webster, 1965)				

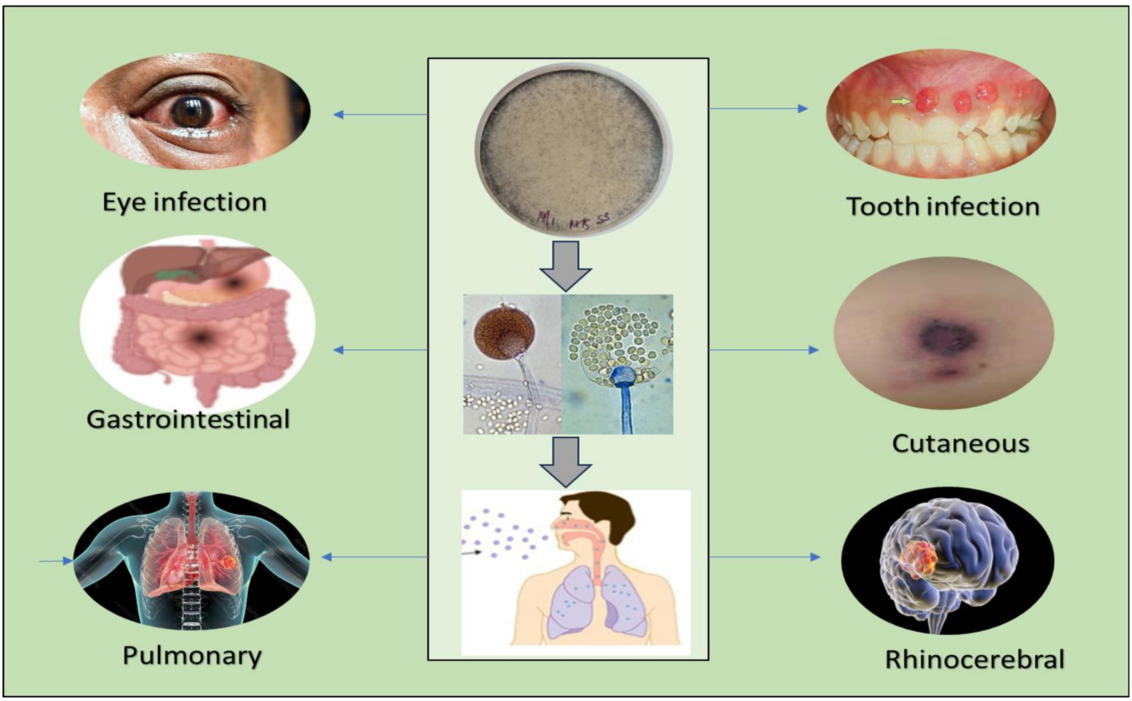

Figure 1: Invasive fungal infections in humans by zygopathogens.

Antifungal Resistance: How defense mechanism is decreasing globally

Resistance to any pathogen refers to a host's failure to any antimicrobial drug in specific amounts (Cowen et al., 2015). In the past few decades, fungal pathogens, specifically human fungal pathogens have developed a strong resistance mechanism against the overuse of antifungal drugs. Several possible factors including inoculum potential, pathogens virulence, and climatic changes might be responsible for the rapid increase in fungal infections worldwide. Additionally, several human diseases are known to develop a high frequency of immuno-compromised patients globally. However, clinical studies based on antifungal resistance explain the complex antifungal resistance based on multiple hosts and microbial adaptations (Cowen et al., 2015; White et al., 2002). The biological response of overused antimicrobial drugs can be observed as genetically mutant and resistant isolates of human fungal pathogens (Miyamoto et al., 2002; Sanglard, 2002). The resistance capabilities of the fungal pathogens primarily depend on the type and frequency of antifungal drugs applied.

To understand the defense, mechanisms of resistance need to be focused on in several ways. However, based on action and mechanism, antifungals can be broadly categorized into three groups: azoles, polyenes, and 5-fluorocytosine (Ghannoum and Rice, 1999). The resistance of these three antifungals can emerge through various mechanisms including over-expressions, gene alterations, cellular changes to reduce the antifungal drug toxicity, mutational changes, and many more.

Azole is primarily known to alter the ergosterol biosynthetic pathway (EBP). The primary fungal cell wall component Ergosterol is responsible for permeability, membrane integrity, stability, enzyme activity, and other physiological and metabolic activities of fungi. The alteration and interruption in EBP allow the accumulation of basic sterols such as 14α-methyl which affects the cellular mechanism (Cowen et al., 2015; Odds et al., 2003). Recent studies have stated that azole drugs primarily target the specific heme proteins which indirectly inhibit the 14α-methyl followed by ergosterols. Azole drugs target Erg 11/Cyp51A also known as lanosterol 14α-demethylase catalyze the removal of 14α-methyl from lanosterol. However, recent studies have demonstrated the potential role of azole antifungals as Erg 11 inhibitors (Beggs, 1983). The important azole antifungal drugs against human fungal pathogens mainly include the original chemical compounds such as econazole and miconazole followed by fluconazole, itraconazole, and ketoconazole. These compounds have emerged as potential antifungal drugs globally in the past few years (Ghannoum and Rice, 1999).

Polyenes are known as the oldest yet effective antifungals to treat widespread fungal diseases. Ergosterol, the cell membrane component of fungi, is primarily affected by the systemic defensive mechanism of polyenes. This antifungal drug attaches to ergosterol, disrupts, perforates, and causes fungal cell death. Amphotericin B/AmB is one of the oldest and most widely used antifungal drugs before the discovery of azoles in the late 1950s. The widely used drug is known for its low resistance and high effect. Additionally, several diseases including those caused by *Cryptococcal meningitis*, *Aspergillus*, and *Candida* have been globally cured by polyene drugs (Ghannoum and Rice, 1999; Sugar, 1987; Wang et al., 2021). Studies related to the mechanism of action of AmB, include several models including Ion Channel-Mediated Membrane Permeabilization which explains AmB's action in the membranes of fungal cells. These actions disrupt the membrane function, and leak across the membrane, causing an imbalance in the cell's internal environment and leading to cell death. Despite AmB's effectiveness, the resistance is found to be neutral to negative in comparison to other antimicrobial agents observed so far. This resistance refractoriness is linked to the mechanism of action involving ion channel formation. However, AmB's ability to form these channels also leads to dose-limiting toxicity, as human cells can also be affected by the same ion channel formation, especially in tissues such as kidneys (Finkelstein, 1973; Gray et al., 2012; Volmer et al., 2010).

Antifungal drugs and resistance to zygopathogens

Zygopathogens mainly including the Mucorales and Entomophthorales are widespread human fungal pathogens studied in the past few decades. Mucormycosis is a fungal infection that typically affects individuals with weakened immune systems, making them more susceptible to the disease (Kauffman, 2004; Smith and Lee, 2022). The mammalian-pathogenic Entomophthoromycota includes genera *Basidiobolus* and *Conidiobolus* (Khan et al., 2001; Mendoza et al., 2015; Muszewska et al., 2014). These species are the causative agents of entomophthoromycosis, an infection primarily affecting humans and lower animals. The infection is usually confined to the subcutaneous tissues and, in rare cases, may involve other organs as well (Mendoza et al., 2015). For mucormycosis treatment, polyene antifungal drugs specifically amphotericin B (AmB) have been globally used so far (Mendoza et al., 2015; Spellberg et al., 2005; Sugar, 2005). Past studies and random patients' history show relatively high resistance to AmB from mucorales, therefore requiring high drug doses, which are often linked to nephrotoxicity and instability conditions (Sipsas et al., 2018). However, lipid formulations of AmB are less nephrotoxic making them potentially more effective than the conventional AmB formulation (Mendoza et al., 2015). Entomophthoramycosis, sub-categorized into Basidiobolomycosis and conidiobolomycosis is caused by *B. ranarum* and *Conidiobolus spp* (*C. coronatus, C. incongruus,* and *C. lampragues*) respectively (Gugnani, 1999). Several past studies based on antifungal sensitivity examinations state high inhibition of *B. ranarum* against azole drugs mainly miconazole and ketoconazole (Mendoza et al., 2015; Saka et al., 2010; Villasco et al., 1966). However, other azole drugs including AmB and fluconazole when given in low doses showed a positive response to the pathogen inhibition and resistance (Randhawa et al., 1994).

Conclusions

Zygomycota infections are known to cause severe infections and diseases in humans. These human pathogenic diseases cause hidden damage and affect millions of lives every year globally. Due to rapid genetic diversity, mutations, and complicated morphological adaptations, insufficient research progress has been observed in the last few years. This review has been attempted to describe the fungal pathogens of Zygomycetes and their relevant diseases caused to humans all over the world. Additionally, the pathogens with updated distribution, new species, and morphological characters have also been reviewed. Host-pathogen interaction and its mechanisms related to Zygomycota have been highly considered. In recent years, the fungal pathogens have progressed, and severity has elevated in the hosts. This study has actively included antibiotic resistance caused due to various factors of human pathogens.

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Plastic Waste : Challenges and mitigation

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Keywords : *Plastic, Biodegradation, Recycling Challenges*

Abstract

Plastic is a necessary component of contemporary life, and throughout the past 50 years, its manufacturing has skyrocketed. The buildup of plastic waste is a major source of pollution for the environment. The biodegradation problem arises from the intrinsic properties of polymers that keep them from dissolving into monomers. While physical and chemical methods have disadvantages, such as harmful byproducts and disposal issues, biological treatments are environmentally safe. The various facets of plastic pollution and its reduction is the main focus of this review. Aspects that are specifically covered include plastic types, recycling challenges, degradation techniques, highlighting research on biodegradation by bacteria, fungi, and algae, and different polymer properties that researchers have examined to gauge degradation worldwide.

1. Introduction

Plastic is an integral part of modern society due to their versatility, durability, and cost-effectiveness (Arutchelvi et al., 2008; Emadian et al., 2017). Since the 1950s, plastic production has increased dramatically, surpassing 400 million metric tons annually as of 2021 (PlasticsEurope, 2022). The primary sources of plastic production include petrochemical-derived polymers such as polyethylene, polypropylene, and polyvinyl chloride. The largest plastic-producing regions include China, North America, and Europe. The primary industries utilizing plastics include packaging (accounting for approximately 40% of total production), construction, textiles, and automotive manufacturing (Geyer et al., 2017). The present review will be focusing on the different aspects of plastic pollution and its mitigation; specifically discussed points are types of plastics, challenges in recycling, methods of degradation, highlighting the studies related with biodegradation by bacteria, fungi and algae, various properties of the polymers studied by researchers for assessment of degradation from the globe.

2. Types of Plastics

Plastics are classified based on their chemical composition and properties. The major types include:

(i) Polyethylene (PE) - PE is the most common plastic and is used in bottles, bags, and packaging. Its high molecular weight and hydrophobic properties make it extremely resistant to degradation (Albertsson & Hakkarainen, 2017).

(ii) Polypropylene (PP) - PP is utilized in textiles, automobile components, and food containers. It is immune to microbiological attack due to its semi-crystalline structure (Shah et al., 2008).

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(iii) Polyvinyl Chloride (PVC) - PVC is utilized in flooring, medical equipment, and pipelines. It has potentially harmful plasticizers and stabilizers that make microbial breakdown difficult (Ghosh et al., 2021).

(iv) Polystyrene (PS) - Polystyrene (PS) is frequently used in packaging, insulation, and disposable cutlery. Its aromatic structure makes it extremely resistant to biodegradation (Yoshida et al., 2016).

(v) Polyethylene Terephthalate (PET) - PET is a common material for synthetic textiles and beverage bottles. It has been discovered that certain bacterial species, such Ideonella sakaiensis, break down PET by secreting the enzyme PETase (Austin et al., 2018).

(vi) Polyurethane (PU) - PU is utilized in coatings, foams, and adhesives. Through enzyme-mediated hydrolysis, several bacterial strains have demonstrated the capacity to break down PU (Howard et al., 2012).

3. Plastic Recycling: Challenges and Opportunities

Global plastic recycling rates are still low, despite of increased awareness. Only over 9% of all plastic garbage produced as of 2021 has been recycled; the remaining 79% has either accumulated in landfills or the environment, and 12% has been incinerated (UNEP, 2021). The barriers to these recycling processes can be summarized as follows –

(i) Technical Restrictions: Mixed materials and chemical additions make many plastic items non-recyclable (Hopewell et al., 2009).

(ii) Economic Restrictions: Because of the expenses associated with collection and processing, recycling is frequently less economical than producing fresh plastic.

(iii) Consumer Involvement: Effective recycling is hampered by inconsistent trash segmentation and a lackluster recycling infrastructure (Ritchie & Roser, 2018).

Government interventions such as plastic bans, extended producer responsibility (EPR), and international agreements like the Basel Convention amendments are crucial in managing plastic waste (UNEP, 2021). More research into biodegradable polymers offers a promising alternative (Narancic et al., 2018). Techniques such as chemical recycling and pyrolysis could enhance plastic waste management (Hopewell et al., 2009). Public awareness campaigns and corporate initiatives to reduce single-use plastics can significantly impact plastic waste reduction (Ritchie & Roser, 2018).

4. Environmental Impact of Plastic Waste

According to Jambeck et al., (2015), an estimated 8 million metric tons of plastic enter the oceans each year, harming marine life through entanglement, ingestion, and habitat loss. Concerns regarding possible health hazards have been raised by the discovery of microplastics, which are produced as bigger plastics break down, in soil, water supplies, and even human blood (Leslie et al., 2022).

Plastic production and degradation contribute to greenhouse gas emissions, exacerbating climate change. The carbon footprint of plastics is estimated at 1.8 billion metric tons of CO2 equivalent annually (Zheng & Suh, 2019).

5. Methods of Plastic degradation

Conventional disposal methods like landfilling and incineration create environmental problems. To reduce the accumulation of plastic waste, several degrading techniques have been investigated, such as chemical and physical methods (Geyer et al., 2017).

(i) Chemical Methods of Plastic Degradation

Plastic Chemical degradation is the process by which polymer chains are broken down into smaller molecules by chemical processes, making it easier to convert them into safer byproducts or reusable materials.

- Hydrolysis Hydrolysis involves the cleavage of polymer chains by water, often accelerated by acids, bases, or enzymes. This method is particularly effective for polyesters such as polyethylene terephthalate (PET) (Kumar et al., 2020).
- Oxidative Degradation Oxidative degradation occurs through exposure to oxygen, ozone, or free radicals. Photodegradation, a subtype of oxidative degradation, relies on ultraviolet (UV) radiation to generate free radicals that break down polymer chains, particularly in polyethylene (PE) and polypropylene (PP) (Sharma & Mudhoo, 2021).
- Solvolysis Solvolysis includes glycolysis, methanolysis, and aminolysis, where solvents break polymer bonds. This method is highly effective in recycling PET and polylactic acid (PLA) (Rahimi & García, 2017).
- Catalytic Depolymerization This process uses catalysts to accelerate polymer breakdown into monomers or useful chemicals. Catalysts such as metal oxides and zeolites have shown promise in the degradation of polyethylene and polystyrene (PS) (Jiang et al., 2019).

(ii) Physical Methods of Plastic Degradation

Physical methods primarily involve mechanical forces and environmental conditions to break down plastic materials into smaller fragments.

- Thermal Degradation Thermal degradation involves heating plastics at high temperatures to break chemical bonds. Pyrolysis, a widely studied thermal degradation process, converts plastics into fuel-like products under anoxic conditions (Singh et al., 2020).
- Ultrasonic Degradation Ultrasonic waves generate cavitation bubbles, leading to mechanical stress and polymer fragmentation. This method has been effective in degrading polymer solutions and films (Tokiwa et al., 2009).
- Mechanical Fragmentation Mechanical processes such as grinding and milling break plastics into micro- and nanoplastics, increasing their surface area for further degradation (Xanthos & Walker, 2017).

- Radiation-Induced Degradation Ionizing radiation, including gamma rays and electron beams, initiates chain scission in polymers, facilitating degradation. This method is particularly effective for sterilization and recycling applications (Ojeda et al., 2011).

(iii) Biological method of plastic degradation

While these chemical and physical processes have drawbacks including hazardous byproducts and disposal problems, biological treatments are safe for the environment. For the degradation of polymers, it is the best option (Moharir & Kumar, 2019).

Although microorganisms play a role in biological processes, numerous studies conducted over the past 30 years have documented the biodegradation of polythene by a variety of bacteria in natural settings; nonetheless, the rate at which microorganisms break down polythene is extremely slow. Several strains have been found over the past 50 years for their capacity to interact with polyethylene and cause some sort of deterioration.

Microorganisms break down this polymer by consuming it and altering its characteristics. (Koutny et al., 2006a; Arutchelvi et al., 2008; Eubeler et al., 2010; Hakkarainen and Albertsson, 2004; Gu, 2003) Physical restrictions on its use by microorganisms include its large molecular weight, lack of functional groups, and insolubility in aqueous media (Arutchelvi et al., 2008).

Polyethylene is most utilized polymer, commonly used for plastic bags and other purposes as it is easy to handle, having light weight, durability and strength (UNEP, 2021). 140 million tons of PE is being produced every year globally (Sivan, 2011). The breakdown of polyethylene by actinomycetes, bacteria, and fungi has been documented in numerous investigations. There is sufficient evidence that micro-organism degrade it, although the full metabolic process is still unknown. This breakdown is caused by the enzymatic actions of both intracellular and extracellular depolymerises (Restprepo et al., 2014).

Nine fungal genera which are *Acremonium, Aspergillus, Chaetomium, Cladosporium, Fusarium, Glioclodium, Mortierella, Mucor, Penicillum and Phanerochaete, and fourteen bacterial genera which are Acinetobacter, Arthrobacter , Bacillus, Brevibacillus, Delftia, Flavobacterium, Micrococcus, Microbacterium, Nocardia, Paenibacillus, Pseudomonas, Rahnella, Ralstonia, Rhodococcus, Staphylococcus, Stenotrophomonas, Streptomyces* have been linked to the breakdown of polythene, according to several investigations. The characteristics of the polythene surface, such as variations in density, degree of branching, and availability of functional groups, determine the capacity of microorganisms to form biofilm on the polyethylene surface (Al-Makhlafi et al., 1994; Cunliffe et al., 1999; Donlan, 2002; Wang et al., 2012).

Not individual strains but a microbial consortium, biodegrade a large number of complex natural and manufactured substances. This is most likely because individual organisms have limited metabolic capacity. Thus, it can be hypothesized that microbial assemblages can more effectively breakdown plastic waste, one of the primary environmental issues facing contemporary countries, even though this area has not received as much attention as plastic degradation by individual microbial strains.

In this context, the biodegradation of xenobiotics and hydrocarbons with the aid of microbial consortia is a well-researched phenomenon (Ali et al., 2021). According to Yu et al. (2019), microorganisms collectively can have greater biodegradation efficiency than single strains, either by removing potentially hazardous breakdown intermediates or by directly participating in biodegradation. Through metabolic cross-feeding or the production of metabolites that promote co-metabolic degradation, individual members of a microbial consortium can also indirectly enhance biodegradation (Hu et al., 2020).

Enzyme binding to the polymer and catalyzing its hydrolytic cleavage results in the enzymatic fractionation of the polymeric chain into low MW molecules such oligomers, dimers, and monomers, which is the first step in the biodegradation of plastic waste. These low MW molecules eventually mineralize into CO2 and H2O as the process advances. According to reports, bacteria, fungi, and algae are efficient microorganisms that can break down polymers like PE and PU (Ali et al., 2021).

There are some studies which reported the biofilm formation and secretion of extracellular polymeric substances by different algal genera, including *Chaetophora, Coleochaete, Aphanochaete, Gloeotaenium, Oedogonium, Oosystis, Oscillatoria, Phormedium, Chroococcus, Aphanothece, Fragellaria, Coeonix, Cymbella, Navicula, Monorhipdium, Chlorella,Closterium, Microcystis* and *Amphora* (Suseela and Tappo, 2007; Sharma et al., 2014; Sarmah and Rout, 2017).These studies claimed that the colonization of larger microorganisms, affects the strength and performance of submerged objects in the water bodies. These biofilm producing organisms may also accelerate the degradation of the polymers (Ford and Mitchell, 1990).

Another study which was conducted to examine the treatment and breakdown of polythene using three distinct kinds microalgae- green algae (*Scendesmes dimorphus*), blue green algae (*Anabaena spiroides*), and diatoms (*Navicula pupula)*, extracted and isolated from household wastewater. The study came to the conclusion that microalgal colonies dominated waste water ecosystems because of the abundance of nutrients, water, and sunlight, and are efficient enough to intiate biodegradation (Kumar et al., 2017).

6. Properties to be assessed for the determination of biodegradation

The properties of polyethylene are affected by microorganisms that can colonize its surfaces in a variety of ways. To determine the degree of biodegradation of the polymer, the following properties are typically tracked for changes: functional groups on the surface, hydrophobicity/hydrophilicity, crystallinity, surface topography, mechanical properties and molecular weight distribution.

(i) Functional group on the surface

Researchers have focused on the following functional groups in their analysis of the polymer's spectral information: carbonyls (1715 cm^1), esters (1740 cm}1), vinyls (1650 cm}1), and double bonds (908 cm}1). Literature studies agree that changes in these groups are typical whenever biological activity on a substrate's surface has been detected. FTIR spectroscopy is typically used to study the nature and occurrence of functional groups on the surface of polyethylene substrates. (Albertsson et al., 1987, 1995, 1998; Albertsson and Karlsson, 1990; Raghavan and Torma, 1992; Orhan and Büyükgüngör, 2000; Volke Sepulveda et al., 2002; Bonhomme et al., 2003; Chiellini et al., 2003; Gilan et al., 2004; Manzur et al., 2004; Hadad et al., 2005; Sudhakar et al., 2008; Artham et al., 2009; Balasubramanian et al., 2010; Nowak et al., 2011; Santo et al., 2012).

It is well acknowledged that the concentrations of these surface functional groups will drop when microbes are present; this is often expressed as a drop in the carbonyl indices. The other widely accepted conclusion in the literature is that the presence of microbes should cause a commensurate rise in the amount of double bonds. Due to the fact that oxidized groups are more readily broken down by microbes (Albertsson et al., 1995) and that they influence microbial attachment by making the surface more hydrophilic (Tribedi and Sil, 2013), it is crucial to investigate the chemistry of polyethylene surfaces. This suggests that using a more oxidized surface as a substrate will accelerate the breakdown of polyethylene.

(ii) Increase or decrease in hydrophilicity / hydrophobicity of the surface

The type, concentration, and exposure of the functional groups of a substance determine whether a surface is hydrophobic or hydrophilic. Depending on the relationship between oxidation and microbial consumption of oxidized groups, two processes can be seen in the degradation of polyethylene. There will be an increase in hydrophilicity if the amount of oxidation caused by abiotic stimuli like UV radiation or enzyme activity is greater than the amount of functional group consumption. On the other hand, a rise in hydrophobicity will be noted if the rate of functional group consumption exceeds the rate of oxidation.

In biodegradation investigations, hydrophobicity is a crucial surface characteristic since the relationship between the hydrophobicity of the microorganisms and the surface will dictate the degree of colonization on the polymer substrate. It is well acknowledged that microbes can more readily colonize surfaces that are more hydrophilic (Al-Makhlafi et al., 1994; Cunliffe et al., 1999; Donlan, 2002; Wang et al., 2012).

The contact angle of a surface with a probe liquid, like water, is typically used to evaluate how hydrophobic a surface is; the more hydrophilic the surface, the lesser the contact angle with water (Sudhakar et al., 2008).

(iii) Polymer consumption

Although the speed of the process can make it extremely challenging to detect, the consumption of a polymer by microbes offers proof of its assimilation. Nonetheless, some research has documented a decrease in sample weight as assessed by CO2 evolution from the samples (Albertsson, 1980; Karlsson et al., 1988; Albertsson and Karlsson, 1990; Seneviratne et al., 2006; Pramila and Ramesh, 2011a) or by gravimetric measurements (Hadad et al., 2005; Sivan et al., 2006; Sudhakar et al., 2008; Artham et al., 2009; Nowak et al., 2011; Tribedi and Sil, 2013), respectively. The method that offers more insight into the consumption of polyethylene by microbes is CO2 evolution, out of the two that are frequently employed. Since it is expected that the polyethylene that microbes consume as a carbon source would ultimately be converted to CO2 during respiration, this technique can be used as an indirect indicator of the quantity of polyethylene that microorganisms have used. Determining the rate of degradation as well as the overall consumption of the polymer is made possible by the constant monitoring of CO2 evolution out of the system. (Albertsson, 1980; Karlsson et al., 1988; Albertsson and Karlsson, 1990; Seneviratne et al., 2006; Pramila and Ramesh, 2011a).

(iv) Topography of the surface

Numerous research studies have demonstrated that when microbes colonize HDPE surfaces, the surface topography typically changes. Common characteristics following microbial attack have been described as the formation of microcolonies of various microorganisms on the polymer's surface (Bonhomme et al., 2003; Gilan et al., 2004; Sivan et al., 2006; Koutny et al., 2006b; Fontanella et al., 2010; Pramila and Ramesh, 2011a; Tribedi and Sil, 2013) and the penetration of hyphal structures (Raghavan and Torma, 1992; Manzur et al., 1997; Volke-Sepulveda et al., 2002). SEM analysis and optical microscopy are methods for examining the surface topography of polythene and determining whether microbes have adhered to its surface (Arutchelvi et al., 2008; Restprepo et al., 2014).

(v) Crystallinity

FTIR, DSC, and XRD techniques are used to detect changes in the crystallinity of polythene (Sudhakar et al., 2008, Balasubramanian et al., 2010). The semi-crystalline structure of polythene is encircled by amorphous areas. To increase the ratio of larger crystals, colonizing microorganisms typically consume the amorphous region of PE first, followed by smaller crystals once these regions are depleted (Raghavan and Torma, 1992; Albertsson et al., 1995; Manzur et al., 1997; Volke-Sepulveda et al., 2002; Sudhakar et al., 2008; Santo et al., 2012).

7. Conclusion and perspective

These days, pollution from the accumulation of plastic garbage is a big environmental concern. The inherent characteristics of polymers prevent them from breaking down into monomers, which is the cause of the biodegradation issue. Actually, non-hydrolyzable manmade polymers cannot be broken down by the microbial enzyme systems. The prevalence and activity of bacteria that break down polymers varies depending on the environmental circumstances. To find out how different microbes can break down polymeric materials and identify their enzymatic-degradation system, more research is required on the biodegradation process and factors.

A designed microbial population may enhance the efficiency of the plastic biodegradation process. Furthermore, modified microbes with function-specific genes integrated into their genome may be possible by applying molecular engineering approaches. When identifying the best microbes for breaking down polymers, molecular methods are essential. According to this perspective, proteomics and genomes should be the main areas of study.

As a new upcycling method, algal biodegradation may be superior to bacterial or fungal biodegradation since it doesn't need a rich carbon source or a particular pretreatment.

The role of free radical-producing algae in promoting the biodegradation of different plastic polymers must be emphasized because of their oxidative stress, which raises the polarity of the plastic polymer and facilitates the biodegradation process.

Poly (lactic acid), polyhydroxylkanoates, and thermoplastic starch are examples of biomass-based biopolymers that exhibit significant promise, particularly for single-use applications like packaging. Their marketing as a "greener" substitute is unwarranted in the absence of functional anaerobic digestion or industrial composting facilities. Finally, there is currently no efficient, cost-effective, environmentally benign, and socially acceptable plastic-degrading method; hence, further research is required to create new technologies for the degradation of plastic waste.

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