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Leveraging Plant Science, Biotechnology and Sustainable Agriculture for a Resilient Future

Nature Light Publications

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Preface

The increasing pressures of climate change, environmental degradation, and global food and health challenges necessitate innovative, interdisciplinary, and sustainable scientific approaches. In this context, the present volume, "Leveraging Plant Science, Biotechnology and Sustainable Agriculture for a Resilient Future," *aims to provide a comprehensive platform for disseminating recent advances and emerging perspectives in plant sciences and allied fields.*

This book brings together contributions from researchers and academicians working across diverse domains, including plant taxonomy and biodiversity, molecular biology and genetics, agricultural biotechnology, climate-resilient agriculture, ethnobotany, phytochemistry, environmental science, and food and nutritional sciences. The chapters reflect both fundamental and applied research, highlighting the role of scientific innovation in addressing contemporary global challenges.

A key focus of this volume is the concept of leveraging scientific knowledge and technological advancements to develop sustainable solutions. The contributions demonstrate how integrative approaches ranging from traditional knowledge systems to modern biotechnological interventions can enhance agricultural productivity, ensure food and nutritional security, and promote environmental sustainability. Special emphasis has been placed on climate change adaptation, resource-efficient agricultural practices, and the utilization of plant-based bioresources for human health and well-being.

This volume is intended for researchers, postgraduate students, and professionals in plant sciences, agriculture, biotechnology, and environmental studies. It is expected to serve as a useful reference for understanding current research trends and identifying future directions in sustainable development.

The editors sincerely acknowledge the valuable contributions of all authors, whose efforts have made this volume possible. We also extend our *gratitude to our respective institutions and colleagues for their continuous support during the compilation of this book.*

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Leveraging Plant Science, Biotechnology and Sustainable Agriculture for a Resilient Future

Table of Content

Section III: Agriculture, Crop Improvement and Sustainable Farming

Section IV: Climate Change, Environment and Ecosystem Studies

Section V: Plant-Based Health, Phytochemistry and Medicinal Sciences

Section VI: Food Science, Nutrition and Nutraceuticals

Section VII: Fungi, Microbiology and Bio-resources

Section VIII: Emerging Technologies and Future Perspectives

Section IX: Interdisciplinary and Societal Perspectives

Lepidagathis mitis Dalzell New Distributional Record from the Northern Western Ghats

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Abstract

This research paper presents a comprehensive botanical investigation of the Lepidagathis mitis Dalzell (Acanthaceae), including its range extension in the northern Western Ghats. According to the still available scientific literature, this species is distributed in limited areas of the study area. Along with this species, the habitat, vegetation, population, and morphology were studied. A critical taxonomic study, encompassing both macroscopic and microscopic observations, along with a basic survey of accessible references, reveals that these species are found as a range extension and a new distributional record of the Indian endemic species.

Keywords: *Lepidagathis mitis* Dalzell, Endemic, New distributional record.

Introduction

One of the large Acanthaceae families that are a part of the Angiosperm orders is Lamiales. The 208 genera in the Acanthaceae family have a worldwide distribution. (POWO, 2024). There are 156 recognized species categories in the genus Lepidagathis Willd., which is a member of the Acanthaceae family and is primarily found in pantropical areas (Patil et al., 2026); (POWO, 2026b). There are 40 species in the genus Lepidagathis in India; notably, 28 of these species are native to the country (Bramhadande & Nandikar, 2023). The Acanthaceae family's genus Lepidagathis is notable for having over 25 species in the tropical forest of Maharashtra's northern Western Ghats (Gaikwad et al., 2014; Deshpande et al., 2016; Bramhadande & Nandikar, 2023; Patil et al., 2026). L. mitis is native to India as well as acknowledged as a Peninsular Indian endemic plant (POWO, 2026a).

We gathered Lepidagathis specimens from the plateaus in the northern regions of the Naneghat trekking sites during our floristic study in Maharashtra's northern Western Ghats. Thorough morphological analysis and these studied taxa were identified by using Flora, Herbarium catalog, monographs, and the deposited herbarium (Hooker, 1885; Cooke, 1908; Singh et al., 2000; POWO, 2025). An investigation and a survey of the scientific literature revealed that this phenomenon has been reported in different regions of India, including Tamil Nadu, Andhra Pradesh, Karnataka, and Maharashtra (Rao & Kumar, 2026). It has also been reported in various regions within Maharashtra state, such as Nagpur, Ahilyanagar, and Jalna. From the Konkan region of the northern Western Ghats, such as Ratnagiri and Sindhudurg (Phunda Ghats) (Image 1) (Cooke, 1908; Singh et al., 2001). In the northern Western Ghats, this species was reported at only two sites, Ratnagiri and Sindhudurg (Phunda Ghats). This species was reported at a new site, the Naneghat trekking path at Pendhari, Anjaneri, Nashik, and Hivare Tarf Minher, Junnar, Pune, and Anjineri hill (Nashik). Studied taxa include range extension and a new distributional record for the floristic study of the northern Western Ghats.

Identification of Lepidagathis species using the following key (Singh et al., 2001).

1. Seeds 2:
    2. Calyx 4 partite:
        3. Bracts not spinous pointed…………………………………… L. mitis
        3. Bracts spinous pointed:
            4. Leaves less than 5 cm long; lower sepal bifid above the middle:
                5. Inflorescence mostly in globular, subradical heads:
                    6. Bracts and sepals densely covered with soft hairs………………L. cristata (Singh et al., 2001).

Material and Methods

Study area: During the floristic investigation, living species were observed and collected from the different localities of NWG. Below are their localities with locations, GPS coordinates, and altitude from sea level.

- **Locality 1**. Naneghat trekking path at Pendhari, Dist. Thane, °29'20.6"N 73°67'58.6" E, altitude 757 m.
- **Locality 2.** Hivare Tarf Minher, Junnar, Pune, 19°18'92.3"N, 73°75'76.2"E, altitude 956 m. (Image 1).
- **Locality 3**. Anjaneri, Nashik, 19°92'15.9"N, 73°57'07.9"E, altitude 961m.
- **Locality 4**. Amba Ghats 16°59'18.8"N 73°47'07.0" E, altitude 650 m.
- **Locality 5**. Masnoli, Ratnagiri 16°56'44.3"N 73°47'22.8"E, altitude 730 m.

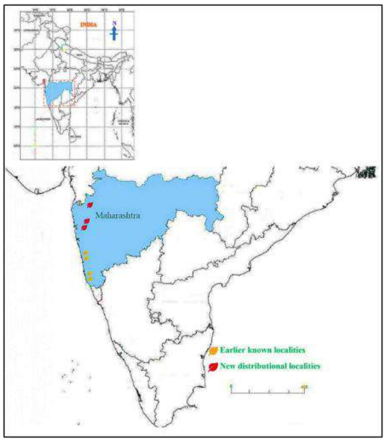

Image 1. Locations of extended distribution populations of Lepidagathis mitis Dalzell

Taxonomy & Morphology

Lepidagathis mitis Dalz. in Hook. Kew J. Bot. 3: 226. 1851; C.B.Cl. in Hook. f. Fl. Brit. India 4: 516. 1885; Cooke, Fl. Pres. Bombay 2: 470. 1958 (Repr.); Sant. in Univ. Bombay Bot. Mem. 2: 71. 1952.

Description

Herbs with short stems and sub-quadrangular branches that spread widely. Leaves are sessile, 2.5–4.5 x 0.5–1.2 cm, linear-oblong, with a subacute or obtuse apex, a constricted base, lineolate above, hairy on nerves below, and typically ciliolate edges. The flowers are 5–8 cm across globose heads, white to pale pink, and heavily speckled with yellowish-brown dots. Capsules are oval, subacute, and 0.5 cm long. Seeds 2 (Image 2) (Singh et al., 2001).

Herbarium Consultation:

The *L. mitis* was identified by utilizing different deposited Herbarium Catalogue specimens No. K000950030 (POWO, 2026a).
Synonyms: *Lepidagathis mitis* var. *latifolia* (Nees) *M.R.Almeida & Lepidagathis mitis* var. subarmata C.B.Cl.(POWO, 2026a).

Common Names: Kumbh.

Flowers & Fruits: November- March.

Distribution: Native to the subcontinent of India.

Distribution in NWG: Ratnagiri and Sindhudurg.

Ecology: Rocky grasslands and seasonally dry tropical areas, especially in the northern Western Ghats of India.

Conservation Status: *Lepidagathis mitis* is currently listed as Not Evaluated (NE) (Rao & Kumar, 2026).

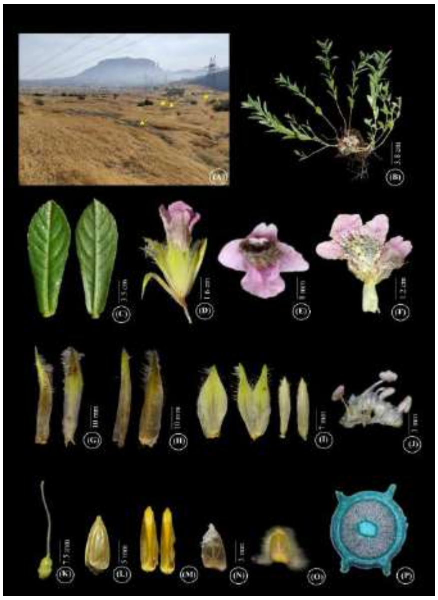

Figure 2. Lepidagathis mitis Dalzell A. Habitat; B. Habit; C. Leaf adaxial & abaxial surface; D. Flower – side view; E. Flower – Front view showing lower lip; F. Corolla split open; G. Outer bracteoles; H. Inner bracteoles; I. Sepals; J. Stamens; K. Gynoecium; L. Capsule; M. Open capsule; N. Seed; O. Seed with hydrated hygroscopic white hairs; P. T.S. stem

Results and Discussion

L. mitis, which was studied in 2024 and 2025, is a distinct plant taxon that is a member of the Acanthaceae family. It is indigenous to the Indian subcontinent. The plant was correctly identified using the Flora of British India, Flora of Maharashtra, Flora of Akola District, Flora of Raigad District, and Flora of Nashik District, all of which were verified by the Herbarium Catalogue specimen No. K000950030 that was placed (Hooker, 1885; Kamble & Pradhan, 1988; Lakshminarasimhan & Sharma, 1991; Almedia, 1996; Singh et al., 2001; POWO, 2026a). Several floras, including the Bombay Flora, the Flora of the Presidency of Bombay, and the Flora of Maharashtra State, were investigated during the review study. The taxa under study have no taxonomic records of any type. Taxa from Pendhari (Thane), Anjaneri hill (Nashik), and Hivare Tarf Minher, Junnar (Pune), that had not been documented, were included in the basic literature assessment of accessible literature. For the northern Western Ghats, it is sometimes asserted that these are new extended records.

Conclusion

In order to expand the record of the floristic diversity of the northern Western Ghats, we investigated the *L. mitis* Angiosperm plant taxa that were first reported in the floristic study of Pendhari (Thane), Anjaneri hill (Nashik), and Hivare Tarf Minher, Junnar (Pune). For easier identification, the description includes scientific notes, photos, and botanical keys from this study report.

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Revision of the *Acacia genera* in India, Including Notes on Introduced Species of *Acacia, Acaciella, Senegalia,* and *Vachellia*

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Abstract

The genus *Acacia* (Family: Fabaceae) includes many medicinally important species distributed across India. About 34 major species have been reported and were traditionally grouped into four sections: *Acacia.* (9 species), *Acaciella* (1 species), *Senegalia* (11 species), and *Vachellia* (13 species). However, molecular phylogenetic and morphological studies revealed that *Acacia* is polyphyletic. Consequently, it was reclassified into smaller, natural genera such as *Acacia* (sensu stricto), *Senegalia*, *Vachellia*, and *Acaciella*. This review summarizes the updated taxonomy using recent literature and databases, focusing on accepted names, nomenclature, and synonymy. These revisions are important for botanical research, biodiversity conservation, forestry, and phytochemical studies.

Keywords: *A., Senegalia, Vachellia, Acaciella*

Introduction

Acacia, a large genus in the Fabaceae family, has over 1,380 species worldwide, with 34 major species reported in India (Singh et al., 2025). Early classifications grouped trees, shrubs, and climbers under Acacia based on bipinnate leaves, spines, and globose or spike-like flowers (Hooker, 1879; Cooke, 1901), creating an artificial, diverse group (Pedley, 1986). Molecular studies showed Acacia is polyphyletic (Maslin et al., 2015), leading to its division into *Acacia*, *Senegalia*, *Vachellia*, *Acaciella*, and *Mariosousa* (Kyalangalilwa et al., 2013). In India, native species are mainly *Senegalia* and *Vachellia*, while true Acacia are mostly Australian. These drought-adapted plants aid soil stabilization, nitrogen fixation, and land restoration, and remain important in phytochemical research (Hassan & Hamdy, 2021).

Methodology

Information Sources

Data for 34 species were collected from MSc, MTech, and PhD theses, along with peer-reviewed publications. Major databases used include Web of Science, PubMed, Google Scholar, ScienceDirect, Wiley Online Library, Springer, and eFloras.

Phylogenetic Basis for Reclassification of the *A.* Complex

Earlier, *Acacia* (sensu lato) included species from Africa, Australia, Asia, and the Americas based on morphology (Hooker, 1879; Pedley, 1986). DNA studies revealed distinct evolutionary lineages, identifying three clades: Australian, African, and American (Maslin et al., 2015). Consequently, *Acacia* was split into *Acacia* (Australian), *Senegalia* (tropical, prickly), *Vachellia* (paired spines, globose flowers), *Acaciella* (Neotropical), and *Mariosousa* (Central America). In India, most species are now *Senegalia* and *Vachellia* (Hurter & Mabberley, 2008).

Results and Discussion

Genus *A. sensu stricto*

This group mainly includes Australian species (Maslin, 2001). It is characterized by phyllodes and absence of large spines (Turnbull, 1986). In India, these species are mostly introduced and used in forestry and industry (Deshpande et al., 2019). Important species include *A. auriculiformis*, *A. mangium*, and *A. mearnsii*, which are widely used for timber and paper production (Midgley & Turnbull, 2003). These species contain phytochemicals like flavonoids and tannins with medicinal properties (Choudhary et al., 2017; Atiya et al., 2022).

Genus *Acaciella*

Acaciella, once included in *Acacia* (Britton & Rose, 1928; Maslin et al., 2015), is now recognized as a distinct evolutionary group (Seigler & Ebinger, 2005; Kyalangalilwa et al., 2013). Mainly found in Central America (Rico-Arce & Bachman, 2006), it comprises shrubs or small trees with bipinnate leaves and globose flowers but no spines. Rare in India, *Acaciella* is key for studying Acacia's evolutionary diversity (Maslin et al., 2015). *Prosopis juliflora* was formerly *A. juliflora* (Burkart, 1976).

Genus *Senegalia*

Senegalia, common in tropical regions including India (Maslin et al., 2015), comprises climbing shrubs or trees with prickles and spike-like flowers (Seigler & Ebinger, 2005). Key species like *S. catechu* (kattha) and *S. senegal* (gum arabic) contain flavonoids, tannins, and alkaloids with antimicrobial and antioxidant properties, and enhance soil fertility via nitrogen fixation (Choudhary et al., 2017; Sprent, 2009).

Genus *Vachellia*

Vachellia, common in dry regions of Africa and Asia (Maslin et al., 2015), features paired spines and globose flowers (Seigler & Ebinger, 2005). Key Indian species *V. nilotica*, *V. leucophloea*, and *V. jacquemontii* provide tannins, medicinal uses, and bioactive compounds like flavonoids and terpenoids, supporting pharmacological activity, soil conservation, and land restoration (Choudhary et al., 2017; Sprent, 2009).

Table 1: List of A. Species Found in India

Species Name	**Authority**	**Accepted Genus**	**Present Name**	**Ref.**
A. aulacocarpa	A. Cunn. ex Benth.	*A.*	_	Singh, et al., 2025
A. auriculiformis	A. Cunn. ex Benth.	*A.*	_	POWO, 2024
A. crassicarpa	A. Cunn. ex Benth.	*A.*	*Racosperma crassicarpum* (A. Cunn. ex Benth.) Pedley	Singh, et al., 2025
A. dealbata	Link	*A.*	*A. decurrens* var. *dealbata* (Link) F. Muell.	Singh, et al., 2025
A. mangium	Willd.	*A.*	*A. holosericea* A. Cunn. ex G. Don	POWO, 2024
A. mearnsii	De Wild.	*A.*	–	BSI, 2012
A. melanoxylon	R. Br.	*A.*	–	CABI, 2023
A. richii	A. Gray	*A.*	–	Singh, et al., 2025
A. saligna	(Labill.) H.L. Wendl.	*A.*	*A. cyanophylla* Lindl.	Singh, et al., 2025
A. juliflora	(Sw.) Willd.	*Acaciella*	*Prosopis juliflora* (Sw.) DC.	Arivazhagan, et al., 2022
A. burkei	Benth.	*S.*	*S. burkei* (Benth.) Seigler & Ebinger	POWO, 2024
A. caesia	(L.) Willd.	*S.*	*S. caesia* (L.) Maslin; *Mimosa caesia* L.	Cooke, 1901
A. catechu	(L.f.) Willd.	*S.*	*S. catechu* (L.f.) P.J.H. Hurter & Mabb.	Hurter & Mabberley, 2008; BSI, 2012
A. chundra	(Roxb. ex Rottler) Willd.	*S.*	*S. chundra* (Roxb. ex Rottler) Maslin; *A. sundra* (Roxb.) DC.	Roxburgh, 1832
A. concinna	(Willd.) DC.	*S.*	*S. rugata* (Lam.) Britton & Rose	Cooke, 1901
A. ferruginea	DC.	*S.*	*S. ferruginea* (DC.) Maslin	Hooker, 1879

A. gageana	Craib	*S.*	*S. gageana* (Craib) Maslin	Maslin, et al., 2019
A. modesta	Wall.	*S.*	*S. modesta* (Wall.) P.J.H. Hurter	Hooker, 1879
A. pennata	(L.) Willd.	*S.*	*S. pennata* (L.) Maslin	BSI, 2012
A. senegal	(L.) Willd.	*S.*	*S. senegal* (L.) Britton	BSI, 2012
A. torta	(Roxb.) Willd.	*S.*	*S. torta* (Roxb.) Maslin	Herbarium JCB., 2024
A. cornigera	(L.) Willd.	*V.*	*V. cornigera* (L.) Seigler & Ebinger	World Flora Online., 2026
A. eburnea	(L.f.) Willd.	*V.*	*V. eburnea* (L.f.) Seigler & Ebinger	Shaikh., 2023
A. farnesiana	(L.) Willd.	*V.*	*V. farnesiana* (L.) Wight & Arn.	Kingsley., 2014
A. horrida	(L.) Willd.	*V.*	*V. horrida* (L.) Kyal. & Boatwr.	Singh, et al., 2025
A. hydaspica	R. Parker	*V.*	*V. hydaspica* (R. Parker) Seigler & Ebinger	Singh, et al., 2025
A. jacquemontii	Benth.	*V.*	*V. jacquemontii* (Benth.) Seigler & Ebinger	Hooker, 1879
A. leucophloea	(Roxb.) Willd.	*V.*	*V. leucophloea* (Roxb.) Maslin	BSI, 2012
A. nilotica	(L.) Delile	*V.*	*V. nilotica* (L.) P.J.H. Hurter & Mabb.	Hurter & Mabberley, 2008
A. planifrons	Wight & Arn.	*V.*	*V. planifrons* (Wight & Arn.) Seigler & Ebinger	BSI, 2012
A. prosopis	Spreng.	*V.*	*V. cineraria* (L.) P.J.H. Hurter & Mabb.	BSI, 2012
A. seyal	Delile	*V.*	*V. seyal* (Delile) P.J.H. Hurter	Singh, et al., 2025
A. sieberiana	DC.	*V.*	*V. sieberiana* (DC.) Kyal. & Boatwr.	Singh, et al., 2025
A. tortilis	(Forssk.) Hayne	*V.*	*V. tortilis* (Forssk.) Galasso & Banfi	POWO, 2024

Conclusion

The traditional *Acacia* genus included a diverse group of species based on morphology. However, molecular studies confirmed that it is polyphyletic, leading to its division into *Acacia*, *Senegalia*, *Vachellia*, *Acaciella*, and *Mariosousa*. In India, most native species now belong to *Senegalia* and *Vachellia*, while *Acacia.* species are mainly introduced. These plants are ecologically and economically important, contributing to soil fertility, land restoration, and medicinal applications. Overall, the reclassification reflects a more accurate understanding of plant evolution. Further research will enhance their use in forestry, medicine, and environmental conservation.

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Documentation of Ethnomedicinal Plants Used by Traditional Practitioners for Human Aliment in Brahmavara Taluka of Karnataka

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Abstract

An ethnomedico-botanical survey was conducted in Brahmavara Taluk, Udupi District, Karnataka, to document traditional medicinal knowledge at risk of being lost. Ten local practitioners were interviewed using semi-structured methods, recording data on practices, diagnosis, treatment, and plant use. A total of 66 plant species from 37 families were identified for treating ailments such as fever, cough, snakebite, skin diseases, malaria, jaundice, and child healthcare. Herbs (44%) were most common, with leaves (55%) being the primary plant part used. Scientific studies support many of these remedies, but further documentation is essential to conserve this valuable traditional knowledge.

Keywords: Brahmavara; Ethnobotany: Medicinal Plants; Udupi

Introduction

Coastal regions of Karnataka show distinctive blend of fauna and flora with the diverse culture. The distinctive biodiversity of this region can be attributed to its location in the foothills of the Western Ghats, recognized as one of the global biodiversity hotspots (Majge et al., 2023). Earlier literature indicates presence of diverse human and plant relations in the coastal region all along the Western Ghats. The documentation on ethnomedicinal plants is also available all along this area. The rapid pace of globalization, urbanization, and overexploitation poses significant threats to traditional medicinal knowledge and medicinal plants.

Studies indicate non interest of younger generations in learning these practices, leading to a gradual disappearance of this invaluable cultural heritage. Hence, the present study was taken up to enlist the medicinal flora used by the practitioners in Brahmavara taluka of Karnataka.

Methodology

Study Area

Brahmavara, a taluka in Udupi district, Karnataka, lies on coastal plains of the Western Ghats. It has tropical climate, heavy monsoon rainfall, and 13 m elevation. Rivers Suvarna and Sita form fertile backwaters. Alluvial and lateritic soils support rice and mangroves. Population was about 131,203 in 2011 (Anonymous, 2026) census.

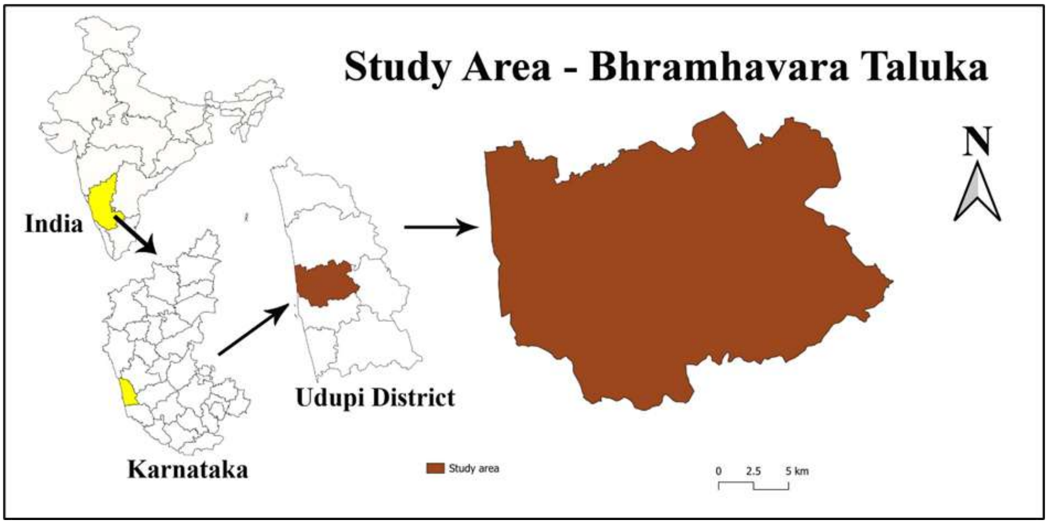

Figure 1 – Study Area

Identification of Traditional Practitioner and Semi Structured Open-Ended Interview

Traditional practitioners were identified through a preliminary survey using convenience sampling and discussions with local stakeholders. Oral consent was obtained, and semi-structured interviews collected qualitative and quantitative data on medicinal plants and practices. Guided walks in informants' gardens ensured accurate plant identification, supplemented by photographs and specimens (Upadhya, 2014). These were later authenticated using authoritative Floras Study details were presented in the table.

Results and Discussion

Traditional Practitioner's Status in Brahmavara Taluk

The study engaged 12 traditional practitioners, of whom 10 shared valuable insights. Similar to observations by Bhat et al. (2019), practitioners in the district and other regions were often hesitant to disclose information. The practitioners ranged in age from 40 to 95 years. Half had no formal education, 25% completed primary school, 17% high school, and only 8% were graduates. Most were farmers, underscoring the rural and agrarian roots of their traditional knowledge.

Botanical Enumeration Ethnomedicinal Plants Documented in the Study

The study documented 66 ethnomedicinal floral species from 36 families, with Apocynaceae (9), Lamiaceae (6), and Fabaceae (5) most represented. Herbs dominated (44%), followed by shrubs (21%), trees (18%), climbers (15%), and epiphytes (2%). Leaves were mainly used (55%), then roots (14%), bark and fruits (12% each). Other parts were also utilized. Practitioners treated diverse ailments, aligning with regional reports, and literature supports the plants' bioactive compounds and medicinal claims (Upadhya, 2014; Bhat et al., 2023)..

Conclusion

This study reveals the rich ethnomedicinal knowledge in Brahmavara, where traditional practitioners treat diverse illnesses using local plants. Proper documentation is essential to preserve this heritage, while awareness on safe usage can strengthen primary healthcare. As a valuable source for drug discovery, further scientific investigation is needed to validate and expand this traditional wisdom.

Acknowledgement

The first and corresponding authors gratefully acknowledge the support of the Head, FPU Department, and the Dean (Forestry), College of Forestry, Sirsi. They also extend sincere gratitude to traditional practitioners for sharing knowledge.

Table 1- Ethnomedicinal plants documented during study

Cl – Climber; H – Herb; E – Epiphyte; S – Shrub; T – Tree; Rz – Rhizome; Lf – Leaf; Fl – Flower; Sd – Seed; B – Bark; St – Stem; Fr – Fruit; Rt – Root; WP – Whole Plant; Lt – Latex;

SN	**Botanical name**	**Common name**	**Habit**	**Parts**	**Disease treated**
Acanthaceae					
1	*Adhatoda beddomei C.B.Clarke*	Adusoge	S	Lf	Cough
2	*Justicia adhatoda* L.	Adu soge	S	Lf	Chicken pox
Amaranthaceae					
3	*Achyranthes aspera* L.	Hirale gida	H	Wp	Snake bite, Wound
4	*Alternanthera sessilis* (L.) R.Br. ex DC.	Honagone soppu	H	Lf	Skin problems
5	*Amaranthus viridis* L.	Chilkere soppu	H	Lf	Ringworm
Annonaceae					
6	*Annona squamosa* L.	Seetaphala	T	Lf	Diabetes
Apiaceae					
7	*Centella asiatica* (L.) Urban	Odelia	H	Lf	Memory, Ring worm
Apocynaceae					
8	*Alstonia scholaris* (L.) R. Br.	Saptaparni	T	B	Malaria
9	*Catharanthus roseus* (L.) G.Don	Nithya pushpa	H	Lf	Nose block
10	*Pergularia daemia* (Frossk.) Chiov.	Talavaran balli	Cl	Lf	Skin problems
11	*Rauwolfia serpentina* (L.) Benth. ex-Kurz	Sarpa gandha	S	Rt	Snake bite
12	*Wrightia tinctoria (*Roxb.) R.Br., Mem. Wern. Soc.	Ale mara	T	Lf	Ringworm
Araceae					
13	*Acorus calamus* L.	Vacha	H	Rt, Rz	Heart disease
14	*Rhaphidophora pertusa* (Roxb.) Schott	Kandodi	Cl	Rt	Joint pain
Arecaceae					
15	*Caryota urens* L.	Bayne mara	T	Sap	Urinary disorder

Table 1- Ethnomedicinal plants documented during study

Cl – Climber; H – Herb; E – Epiphyte; S – Shrub; T – Tree; Rz – Rhizome; Lf – Leaf; Fl – Flower; Sd – Seed; B – Bark; St – Stem; Fr – Fruit; Rt – Root; WP – Whole Plant; Lt – Latex;

SN	Botanical name	Common name	Habit	Parts	Disease treated
Aristolochiaceae					
16	*Aristolochia indica* L.	Arista	Cl	Rt	Skin disease
Asteraceae					
17	*Parthenium hysterophorus* L.	Congress gida	H	Lf	Malaria
Calophyllaceae					
18	*Calophyllum inophyllum* L.	Surahonne	T	Sd	Wound healing
Caricaceae					
19	*Carica papaya* L.	Pappaya	S	Lf	Dengue
Celastraceae					
20	*Celastrus paniculatus* Willd.	Kariganne	S	Sd oil	Abdominal disorder
Cluciaceaea					
21	*Garcinia indica* Choisy	Murin mara	T	Fr	Diarrhea
Costaceae					
22	*Costus speciosus* (J.Koenig) Sm.	Arati Kundige	H	Rz	Urinary infection
Crassulaceae					
23	*Kalanchoe pinnata* (Lam.) Pers.	Bryophyllum	H	Lf	Kidney stone
Euphorbiaceae					
24	*Jatropha curcas* L.	Kadaharalu	S	Lt	Skin diseases
Fabaceae					
25	*Clitoria ternatea* L.	Shanka pushpa	Cl	Fl	Skin problems
26	*Mimosa pudica* L.	Nachike mullu	H	Lf, Rt	Urinary problems
27	*Senegalia rugata* (Lam.) Britton & Rose	Sige	Cl	Fr	Skin disorders, Dandruff

Table 1- Ethnomedicinal plants documented during study

Cl – Climber; H – Herb; E – Epiphyte; S – Shrub; T – Tree; Rz – Rhizome; Lf – Leaf; Fl – Flower; Sd – Seed; B – Bark; St – Stem; Fr – Fruit; Rt – Root; WP – Whole Plant; Lt – Latex;

SN	Botanical name	Common name	Habit	Parts	Disease treated
28	*Tamarindus indica* L.	Hunase	T	Sd	Ulcers
Lamiaceae					
29	*Ocimum tenuiflorum* L.	Tulasi	H	Lf	Respiratory diseases
30	*Anisomeles malabarica* (L.) R.Br. Sims.	Karitumbi	S	Lf	Skin disorder
31	*Coleus amboinicus* Lour.	Dodda pattre	H	Lf	Cough, cold
32	*Gmelina arborea* Roxb.	Shivni	T	Rt, B	Digestion
33	*Leucas aspera* (Willd.) Link	Tumbe gida	H	Fl	Cold
34	*Tectona grandis* L.	Tega	T	Bs	Wounds, Skin problems
35	*Vitex negundo* L.	Nikki kodi	S	Lf	Cough
Lauraceae					
36	*Litsea glutinosa* (Lour.) C.B.Rob.	Bollybeech	T	B	Diarrhea, Dysentery
37	*Persea macrantha* Nees	Gulamavu	T	Lf	Dandruff
Liliaceae					
38	*Asparagus racemosus* Willd.	Shatavari	S	Rt	Urinary diseases
Loganiaceae					
39	*Strychnos nux-vomica* L.	Kasan gida	T	B, Sd	Neuralgic disorders
Lythraceae					
40	*Punica granatum* L.	Dalimbe	T	Fr	Diarrhea
Malvaceae					
41	*Bombax ceiba* L.	Boorga	T	B, Fl	Diarrhea
42	*Thespesia populnea* (L.) Sol. ex-Correa	Portia mara	T	Lf	Fever

Table 1- Ethnomedicinal plants documented during study

Cl – Climber; H – Herb; E – Epiphyte; S – Shrub; T – Tree; Rz – Rhizome; Lf – Leaf; Fl – Flower; Sd – Seed; B – Bark; St – Stem; Fr – Fruit; Rt – Root; WP – Whole Plant; Lt – Latex;

SN	Botanical name	Common name	Habit	Parts	Disease treated
Melastomataceae					
43	*Memecylon randerianum* S.M.Almeida & M.R.Almeida	Gandu kepala	S	Lf	Skin diseases
44	*Memecylon umbellatum* Burm.f.	Valle kodi	S	Fr	Skin infections
Meliaceae					
45	*Azadirachta indica* A. Juss.	Bevu	T	Lf, B	Skin disorder
Moraceae					
46	*Artocarpus hirsutus* Lam.	Hebbalasu	T	B, Fr	Ulcers
47	*Artocarpus lacucha* Buch.-Ham.	Vate huli	T	Fr	Dysentery
48	*Ficus racemosa* L.	Atti	T	B	Diabetes
Musaceae					
49	*Ensete superbum* Roxb.	Kallu bale	H	Sd	Kidney stone
Myrtaceae					
50	*Syzygium caryophyllatum* (L.) Alston	Kunt nerale	T	Sd	Diabetes
Nyctaginaceae					
51	*Boerhavia diffusa* L. nom. Cons	Punarnava	H	WP	Jaundice
52	*Bougainvillea glabra* Choisy	Buganaville	S	Lf	Cough, cold
53	*Mirabilis jalapa* L.	Madhayana mallige	H	Rt	Leukorrhea
Orchidaceae					
54	*Rhynchostylis retusa* (L.) Blume	Mara bale	EP	Lf	Ear pain
Oxalidaceae					
55	*Oxalis corniculata* L.	Pullampurche	H	Lf, St	Diarrhea, Dysentery

Table 1- Ethnomedicinal plants documented during study

Cl – Climber; H – Herb; E – Epiphyte; S – Shrub; T – Tree; Rz – Rhizome; Lf – Leaf; Fl – Flower; Sd – Seed; B – Bark; St – Stem; Fr – Fruit; Rt – Root; WP – Whole Plant; Lt – Latex;

SN	Botanical name	Common name	Habit	Parts	Disease treated
Phyllanthaceae					
56	*Aporosa cardiosperma* (Gertn.) Merr.	Haale mara	S	Lf, B	Skin disorder
Piperaceae					
57	*Piper longum* L.	Hippali	Cl	Fr	Cough
Rubiaceae					
58	*Chassalia curviflora* (Wallich) Thwaites	Vellakurunji	S	Lf	Snake, insect bite
59	*Ixora coccinea* L.	Keskar	S	Fl	Indigestion
60	*Neolamarckia cadamba* (Roxb.) Bosser	Kadamba	T	B	Chicken pox
Rutaceae					
61	*Aegle marmelos* (L.) Corrêa	Bilva	T	B	Diarrhea
62	*Zanthoxylum asiaticum* (L.) Appelhans, Groppo & J.Wen	Jummana kayi	S	Rt	Malaria
Scrophulariaceae					
63	*Bacopa monnieri* (L.) Pennell	Brahmi	H	WP	Enhance memory
Zingiberaceae					
64	*Alpinia calcarata* (Andrews) Roseoe	Rasna	H	Rz	Asthma
65	*Curcuma longa* L.	Arishina	H	Lf, Rz	Skin problems
66	*Zingiber zerumbet* Roscoe.	Kallu shunti	H	Rz	Diarrhea

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Study of Commercially Marketed Ethnomedicinal Plants in Belagavi Region of Karnataka, India

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Abstract

Belagavi district in Karnataka has rich cultural and medicinal traditions. A study interviewing 12 crude drug shop vendors documented 64 marketed medicinal plant species. Plant parts sold included stems (30%), fruits (22%), seeds (13%), leaves (10%), whole plants, and underground parts. Piper nigrum (fruits) was the most sold, followed by *Terminalia bellrica* and *Tinospora cordifolia*. Shops source plants locally and from interstate suppliers, with 80% of local plants collected from the wild. Vendors also sell packaged herbal products but avoid sharing financial details. They note rising demand, suggesting cultivation of medicinal plants as a sustainable way to meet market needs and conserve biodiversity.

Keywords: Medicinal plant, Belagavi, Crude drug, Key informant, Traditional practitioner

Introduction

India has one of the richest plant-based medical traditions, with around 20,000 species used for medicinal purposes (Kamboj, 2000). Over the past few decades, the world has witnessed a shift from synthetic drugs to herbal medicine, appreciated for its efficacy against new diseases (Upadhya, 2014). India's exports of medicinal plants and herbal products, (including AYUSH products), reached about $690 million in 2024–25. Medicinal plants support traditional medicine and the herbal industry while ensuring livelihood and health security for millions (Zamani et al., 2025). Documentation of commercially sold medicinal plants in Belagavi district has been lacking. Hence, this study was undertaken to list the medicinal plants sold in the region.

Methodology

Study Area

Belagavi is one of the largest districts in northwestern Karnataka, Southern India (15°23 to 16°58' N. and 74°5' to 75°28' E). It covers 13,415 sq. km and shares state borders with Goa and Maharashtra. Approximately, 75% of overall population is residing in rural parts of the Belagavi district. People of diverse religions, castes, and tribes enrich its ethnic diversity, relying mainly on agriculture for livelihood (Upadhya 2014).

Identification and Interviews of Crude Drug Shops

Crude drug shop vendors were considered key informants for this study. Shop addresses were collected using the snowball sampling technique, and only vendors with permanent establishments were included. The study's aims and objectives were explained in the language known to them, and consent was secured prior to the interviews. Information was gathered through open-ended interviews. Marketed medicinal plants were identified by their parts and confirmed to botanical names, which are listed in the results section.

Results and Discussion

Twelve crude drug shops in Belagavi district were surveyed, documenting 64 medicinal plant species from 37 families. Fabaceae was the most represented family with 12 species, while Lamiaceae, Apocynaceae, Myrtaceae, Rutaceae, and Solanaceae had three species each. The commonly traded plants matched those listed by Goraya and Ved (2017) as India's traded medicinal plants.

Table 1: List of medicinal plants traded in crude drug shops

Sl. No.	Plant Species	Family
1	*Abrus precatorius* L.	Fabaceae
2	*Acacia catechu* (L.f.) Willd.	Fabaceae
3	*Acacia concinna* DC.	Fabaceae

4	*Acorus calamus* L.	Araceae
5	*Aegle marmelos* (L.) Corrêa	Rutaceae
6	*Anacardium occidentale* L.	Anacardiaceae
7	*Andrographis paniculata* (Burm.f.) Nees	Acanthaceae
8	*Aristolochia indica* L.	Aristolochiaceae
9	*Asparagus racemosus* Willd.	Asparagaceae
10	*Azadirachta indica* A.Juss.	Meliaceae
11	*Boswellia serrata* Roxb	Burseraceae
12	*Butea monosperma* (Lam.) Taub.	Fabaceae
13	*Cassia fistula* L.	Fabaceae
14	*Centella asiatica* (L.) Urban	Apiaceae
15	*Chlorophytum sp.*	Asparagaceae
16	*Chrysopogon zizanioides* (L.) Roberty	Poaceae
17	*Cinnamomum verum* J. Presl	Lauraceae
18	*Coleus barbatus* (Andrews) Benth. ex G.Don	Lamiaceae
19	*Commiphora wightii* (Arn.) Bhandari	Burseraceae
20	*Curculigo orchioides* Gaertn.	Hypoxidaceae
21	*Curcuma longa* L.	Zingiberaceae
22	*Datura metel* L.	Solanaceae
23	*Eclipta prostrata* (L.) L.	Compositae
24	*Elettaria cardamomum* (L.) Maton	Zingiberaceae
25	*Entada rheedei* Spreng.	Fabaceae
26	*Eucalyptus globulus* Labill.	Myrtaceae
27	*Ficus religiosa* L.	Moraceae
28	*Garcinia indica* Choisy	Cluciaceae

29	*Glycyrrhiza glabra* L.	Fabaceae
30	*Gymnema sylvestre* (Retz.) R.Br. ex Sm.	Apocynaceae
31	*Hemidesmus indicus* (L.) R. Br. ex-Schult.	Apocynaceae
32	*Holarrhena pubescens* (Buch. -Ham.) Wall. ex G. Don	Apocynaceae
33	*Indigofera tinctoria* L.	Fabaceae
34	*Justicia adhatoda* L.	Acanthaceae
35	*Lawsonia inermis* L.	Lythraceae
36	*Mucuna pruriens* (L.) DC.	Fabaceae
37	*Myristica fragrans* Houtt.	Myristicaceae
38	*Narthex asafoetida* Falc. ex Lindl.	Apiaceae
39	*Ocimum tenuiflorum* L.	Lamiaceae
40	*Phyllanthus emblica* L.	Phyllanthaceae
41	*Piper longum* L.	Piperaceae
42	*Piper nigrum* L.	Piperaceae
43	*Plantago ovate* Forst.	Plantagiaceae
44	*Plumbago zeylanica* L.	Plumbaginaceae
45	*Pongamia pinnata* (L.) Pierre.	Fabaceae
46	*Prunus amygdalus* (Mill.) D.A.Webb	Rosaceae
47	*Pterocarpus santalinus* L.	Fabaceae
48	*Ricinus communis* L.	Euphorbiaceae
49	*Ruta chalepensis* L.	Rutaceae
50	*Santalum album* L.	Santalaceae
51	*Sapindus laurifolius* Vahl	Sapindaceae
52	*Saraca asoca* (Roxb.) Willd.	Fabaceae
53	*Sida acuta* L.	Malvaceae

54	*Solanum nigrum* L.	Solanaceae
55	*Strychnos nux-vomica* L.	Loganiaceae
56	*Syzygium aromaticum* (L.) Merrill & Perry	Myrtaceae
57	*Syzygium cumini* (L.) Skeels	Myrtaceae
58	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae
59	*Terminalia chebula* Retz.	Combretaceae
60	*Tinospora cordifolia*	Menispermaceae
61	*Tribulus terrestris* L.	Zygophyllaceae
62	*Vitex negundo* L.	Lamiaceae
63	*Withania somnifera* (L.) Dunal	Solanaceae
64	*Woodfordia fruticosa* (L.) Kurz	Lythraceae

Various parts of medicinal plants, such as stem, leaf, fruit, seed, whole plant, flower, underground parts, exudates, and oil were sold in crude drug shops. Among these, the stem (30%) of different species was sold the most, followed by fruit (22%), seed (13%), underground parts (12%), and leaf (10%).

The selling cost of medicinal plants varies from shop to shop. Prices depend on the quantity purchased, availability, and the medicinal importance of the plant. Shop vendors typically sell anywhere from 1 gram to 100 kilograms of crude medicinal plant drugs, depending on customer demand and availability. When customers purchase or order bulk quantities of raw drugs, vendors often reduce their profit margin and lower the selling price. *Piper nigrum* (fruits) was the highest sold crude drug in the shops followed by *Terminalia bellrica* and *Tinospora cordifolia*.

If a customer requests a specific medicinal plant that is not available in the shop, vendors arrange to supply it upon receiving an advance payment. In addition to crude drugs, these shops also market packaged products from various local and other herbal pharmacy companies.

Crude drugs (plant parts) are stored in plastic containers. All shops surveyed had racking facilities to organize containers, which were labelled with local, commercial, or coded names for easy identification. Moderate cleanliness was maintained across all shops.

Two supply channels were identified for medicinal plants in Belagavi's crude drug shops: wholesale suppliers (within and outside the state) and local markets, collectors, and cultivators. Vendors stressed that orders must be placed early, with deliveries made via rail, road, or courier. About 80% of locally sourced plants came from wild resources. While vendors avoided sharing financial details, they noted rising demand. Cultivating medicinal plants was highlighted as a sustainable way to meet market needs and reduce overexploitation.

Conclusion

Present study documented medicinal plant species sold in crude drug shops and most plants were sourced from wild collections, raising concerns about sustainability. Vendors noted a growing market demand, suggesting that cultivation of medicinal plants is the best way to balance commercial needs with conservation. This approach can safeguard biodiversity while supporting local livelihoods.

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Exploring Ethnobotanical Applications of *Syzygium* Species in India

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Abstract

Floral diversity strongly aligns with ethnobotanical use, and the genus *Syzygium* (Myrtaceae) shows remarkable heterogeneity with 102 species in India, including 44 endemics in the Western Ghats and Northeast. Well-known species like S. aromaticum, *S. cumini*, and *S. jambos* provide edible fruits and medicinal parts used in traditional systems. Other species treat ailments such as arthritis, diabetes, and skin diseases in folklore medicine. Many evergreen *Syzygium* trees are valued ornamentals, while their durable timber is widely used in construction and woodcraft. Overall, the genus demonstrates extensive ethnobotanical potential.

Keywords: *Syzygium*, Ethnobotany, Endemic, India.

Introduction

Study of relationship which is always changing with time is Ethnobotany. In India the relationship and the use of plants were documented in different periods and various forms. The periodic documentation over the time also aid to understand the dynamics of the relationship between man and plants.

India possesses a wealth of plant-based traditional knowledge. A multitude of plants and plant parts were utilized as food, timbers, fuel wood, Non-Timber Forest Products (NTFP), Micine, cosmetics, spices, and many more. This knowledge exists in codified (documented) and non-codified (verbal) form in India. This review chapter aims to examine the published ethnobotanical knowledge, present in India for the genus *Syzygium*.

Methodology

A systematic search was conducted across various search engines viz., PubMed, Scopus, Google scholars, and Web of Science, etc., using the keywords *Syzygium*, ethnobotany, India, and ethnobotany, and medicinal uses. The Boolean operators (AND, OR) were applied to refine results. The relevant results were compiled and presented in the form of tables.

Observation

Genus *Syzygium* (family Myrtaceae) consists approximately 1200 species and is the 16th largest genus in the woody flowering plant kingdom. The species of the genus is distributed throughout South- East Asia to the Pacific Islands (Tarigan et al., 2021). In India *Syzygium* genus is represented by 102 species and nearly half of the species (44) were endemic (Dey et al., 2022). This indicate that several species have the origin in Indian continent (Ahmad et al., 2016).

Many *Syzygium* species are evergreen trees or shrubs valued for glossy foliage and edible fruits, consumed fresh or processed into jams and jellies. They thrive from sea level to 800 m, tolerating temperatures from –20°C to 48°C and rainfall above 900 mm. Adaptable to diverse soils—including lateritic, alluvial, sandy, marl, and limestone—some species also withstand salinity, flourishing best in deep, nutrient-rich, well-drained soils (Nigam et al., 2012).

Prominent tree species in *Syzygium* genus, are *S. cumini, S. aromaticum, S. aqueum, S. samarangense, and S. guineense*, etc., which have been diverse ethnobotanical usage. Various parts of these plants, viz., fruits, leaves, barks, stem barks, seeds, and flower buds, offer different benefits including Micinal use.

Ethnobotany of *S. cumini*

Syzygium cumini, known as, black plum, Indian blackberry, Java plum, Malabar plum, Jambolana or Jambul, famous for violet-dark blue in coloured delicious edible fruits. The raw mature fruits are usually sweet to taste with an acrid, sour, slightly acidic flavour. Ripened fruits are eaten raw and it holds special significance as the "fruit of the gods" among Hindus (Kamble et al., 2023). Fermented fruits were used to produce alcoholic beverages such as brandy, wine and a refined beverage called as "Jambava" in Goan culture. The fruits of this tree are liked by both wild and domestic animals and birds. Table 1 represent the Medicinal uses of this tree.

Table 1 – Ethno-Medicinal uses of S. cumini

Part used	**Ethnobotanical use**
Bark	Diabetes, dysentery, jaundice, repeated abortion, wounds, acute

Part used	Ethnobotanical use
	mastitis, asthma, blood pressure, constipation, gonorrhoea, hepatitis, internal haemorrhages, nephritis, nephrolithiasis, piles, liver tonic, strengthen gums and teeth, ringworm infection (head), headache, cough, inflammation, constipation
Fruit	Diabetes, liver tonic, strengthen gum and teeth, good lotion in removing ringworms from the head, fatigue, stomach ache, mouth odour, dysentery, increases appetite, giddiness, cough, inflammation, ringworm gastric problems
Leaves	Diarrhoea, strengthening the teeth and gums, treat dysentery with bloody discharge, antidote in centipede bite and opium poisoning, tooth ache
Root	Spermatorrhoea, diarrhoea
Seed	Diabetes, dysentery, astringent to bowels, cough, cold, fever, skin rashes, mouth ulcers, throat ulcers, genitourinary tract ulcers (caused by *Candida albicans*)
Young leaves	Amoebiasis, bleeding piles, ulcers, cold, hyperacidity, haemorrhagic dysentery, miscarriage, stomach cramp

Several Syzygium species are native to India and have a wide distribution, while others have been introduced into the country (Cock and Cheesman, 2018; Hegde, 2004). The ethnobotanical uses of such species were elaborated in table 2.

Table 2 - Ethnobotanical uses of important Native and Introduced Syzygium species in India

SN	Species Name	Purpose	Part used	Ethnobotanical use
1	*Syzygium caryophyllatum* (L.) Alston	M	Fruit	Acidity in stomach
			Root bark	Eye infection
			Leaves	Skin allergy
		C	Fruits	Edible
		M	Bark	Aphthae, Bums,
			Root	Diarrhoea, Postnatal treatments

			Young leaves	Debility, Sprains, Amoebiasis, Disorders of phlegm, Dysuria, Gonorrhoea, Leucorrhoea, Nephrolithiasis, Haemorrhagic dysentery, Diabetes
2	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	M	Flower buds	Warming and stimulating agent
			Flower buds	Diarrhoea, liver, stomach ailments, nerve stimulant, flatulence, nausea, vomiting, arthritis, cholera, cough, diarrhoea, ear problems, impotence, jaundice, otorrhoea, paralysis, polyuria, sprains, stomachic, syphilis, typhoid
			Flower buds	Tooth ache, pain and gum problems.
3	*Syzygium jambos* (L.) Alston	M	Bark	Dysentery in cattle, Jaundice
			Root	Expectorant, Stomach ache
			-	Haemorrhages, syphilis, leprosy, wounds, ulcers, lung diseases
		O	Tree	Tropical gardens and parks
		C	Fruit	Edible, stewed, turned into jams, jellies, desserts
		M	Fruit	Liver and brain tonic, diuretic,
			Bark	Asthma, bronchitis and hoarseness
			Leaves	Febrifuge, diabetes
			Seeds	Dysentery, diarrhea, and catarrh
			Flowers	Fever
		Otr	Bark	Tannin extracted (7 – 12.4 %)
			Fruits	Alternative to water from rose petals

4	*Syzygium malaccense* (L.) Merr. & L.M.Perry	M	Bark	Haemorrhagic dysentery
			Fruit, leaves	Miscarriage
			Bark, leaves, root & seeds	Astringent, itching, alleviate edema, diuretic, cracked tongue, blood pressure, antibiotic, and respiration
5	*Syzygium samarangense* (Blume) Merr. & L.M.Perry	M	Bark, leaf, seed, fruit	Various biological activities Brain problems, Liver problems, digestive, fever, dry cough, astringent
			Leaf	Diarrhoea, Cracked tongues, headaches, diabetes and cough
			Root bark	Treat dysentery and amenorrhea
		Otr	Leaf	Bath lotions
		T	Wood	Construction
6	*Syzygium aqueum* (Burm.fil.) Alston	M	Leaves	Antibiotic and childbirth pain
			Leaves	treat mouth ulcers
			Root	Itching and Reduce swelling
			Bark	Thrush
			Fruit, leaf and bark	Fever, liver detoxification, headaches, digestive issues, diabetes, lower cholesterol, cancer
		O	Tree	Cultivated in Home gardens and parks

C – Culinary; M – Medicinal; O – Ornamental; Otr – Other uses; T – Timber

Conclusion

Many species of *Syzygium* are commercially cultivated, and many are harvested from natural populations in India. Documentation of their ethnobotanical uses supports value-added applications and can provide additional income to farmers in this country. Therefore, this review contributes to the conservation of traditional knowledge reported by several researchers.

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Comparative Study of Wetland Grass Diversity in Ambazari and Mangli Lakes, Nagpur, Maharashtra

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Abstract

In Nagpur, wetlands such as Ambazari and Mangli Lake represent important ecological landscapes that sustain grass diversity and support local biodiversity. Ambazari Lake, located in an urban area, and Mangli Lake, situated in a semi-natural landscape, represent contrasting wetland environments in Nagpur, Maharashtra. This study investigates a comparative analysis of wetland grass diversity and ecology in these two lakes. It examines biodiversity assessment and taxonomic description of grass species to better understand their adaptive strategies and ecological significance. The herbarium collection provides a permanent record of species diversity, supporting future research. Soil and sediments samples were analysed for pH, moisture, texture, organic matter, and nutrient content. Shannon diversity and IVI indices revealed species dominance and distribution patterns across microhabitats, complementing morphological and anatomical adaptations. The findings highlight differences in species richness, ecological functions, and resilience to anthropogenic pressures, reflecting contrasts between urban impacts and rural conditions. This research contributes baseline data for wetland biodiversity management in Nagpur, Maharashtra and underscores the importance of comparative ecological studies in guiding sustainable conservation practices.

Keywords: Wetland grasses, Biodiversity management, Ecological indices, Soil and Sediment properties, Ambazari Lake, Mangli Lake.

Introduction

Wetlands are ecosystems where land is regularly covered by water. They form transitional zones between terrestrial and aquatic environments and include habitats such as marshes, swamps, and wet grasslands. These areas are ecologically important because their water dynamics and biological communities distinguish them from dry land and open water systems. In tropical and subtropical regions, freshwater wetlands are particularly noteworthy for their floristic richness and capacity to sustain aquatic and semi-aquatic communities that are often sensitive to environmental change [1]. Among wetland plant communities, grasses belonging to the family Poaceae occupy a position of paramount ecological importance. They form the structural and functional backbone of many wetland systems, contributing substantially to nutrient cycling, sediment stabilisation, and the provision of food and shelter for diverse fauna [2].

Nagpur district, located in the Vidarbha region of Maharashtra, is enriched with several urban and rural wetlands, many of which are under varying degrees of anthropogenic stress. Among these, Ambazari Lake and Mangli Lake represent two ecologically distinct yet geographically proximate wetland ecosystems. Grasses are particularly reliable bioindicators of wetland health. Their species composition, diversity indices, and structural attributes respond measurably to changes in water level, nutrient loading, soil physicochemical conditions, and land-use patterns in the surrounding zones [3]. Despite this, systematic comparative investigations of wetland grass communities in the Nagpur region remain sparse, and datasets on the taxonomic identity, ecological indices, and adaptive characteristics of grasses in these lakes are largely absent from the scientific literature.

Objectives

The present chapter is organized around five core objectives:

- Biodiversity and ecological assessment of wetland grasses at both sites
- Taxonomic description of recorded grass species
- Herbarium preparation and documentation
- Analysis of soil-plant relationships and sediment properties
- Evaluation of conservation and restoration potential.

Together, these dimensions provide a holistic ecological profile of the grass flora inhabiting the wetland margins of Ambazari and Mangli lakes.

Field Surveys and Specimen Collection

Systematic field surveys were conducted at both lakes. Grass specimens were collected using standard botanical procedures, specimens were identified using standard taxonomic keys, then pressed, dried, and mounted on herbarium sheets following protocols established by the Botanical survey of India [4].

Soil and Sediment Analysis

Composite soil and sediments samples were collected, air-dried, and stored in clean polyethylene bags prior to laboratory analysis. Soil pH, moisture, temperature, organic matter and nutrients were tested to study soil-plant relationship.

Ecological Analysis

Quantitative vegetation analysis was performed using 1m × 1m quadrats. For each species within a quadrat, frequency, abundance, were recorded following standard phytosociological protocols. The Relative Frequency (RF), Relative Abundance (RA) were computed, and Importance value index (IVI) was derived as the sum of these three relative parameters for each species. Species diversity was assessed using Shannon-Wiener diversity index (H'), Species richness (S), and Evenness (J') [5].

Results and Discussion

Taxonomic Composition of Wetland Grass Species

A total of 13 species, representing 13 genera were documented across both study sites during the investigation period. Ambazari Lake supported 5 species, while Mangli Lake supported 11 species, with 3 species common to both sites. The Dominant genera at Ambazari lake included *Poa trivialis*, *Cynodon dactylon* and *Dichanthium aristatum*. Whereas Mangli Lake was characterised by a richer assemblage including *Echinochloa colona, Paspalidium flavidum* and *Cynodon dactylon.*

Ecological Indices

Using the Shannon Diversity Index (H′), Mangli Lake showed higher diversity (2.10) than Ambazari Lake (≈1.52), indicating greater species richness and a more varied distribution of individuals. Pielou's Evenness Index (J′) revealed high evenness at both sites, with Ambazari (~0.95) slightly higher than Mangli (~0.88), suggesting a more balanced abundance among fewer species. Overall, Mangli Lake demonstrates greater diversity and richness, while Ambazari shows higher evenness. These variations highlight differences in community structure between the two wetlands, likely influenced by environmental conditions, hydrology, and habitat characteristics affecting grass species composition.

Conservation and Restoration Potential

The findings of the present study carry significant implications for the conservation and management of wetland biodiversity in Nagpur. Restoration initiatives at Ambazari Lake should prioritise nutrient load reduction through improved sewage treatment and the establishment of buffer zones along the lake margin to intercept non-point source pollutants from urban catchment [6]. Mangli Lake, by virtue of its higher species diversity and the presence of ecological wetland grasses, require active conservation attention. Seasonal drying of lake margins, which supports the germination of annual grass species and maintains the diversity of the littoral community, should be preserved as a natural hydrological process and should not be altered by artificial water level management [7].

Conclusion

Mangli Lake exhibits greater species richness and diversity, whereas Ambazari Lake shows higher evenness among fewer species. These variations reflect the role of environmental factors and habitat conditions in shaping wetland plant communities, highlighting the importance of targeted conservation and management strategies to maintain ecological balance and sustainability.

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Assessment of Morphological Parameters and Soil Microbial Dynamics in Different Growing Conditions of *Saraca asoca*

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Abstract

Saraca asoca (Seeta ashoka), an evergreen medicinal tree of the Fabaceae family, was studied across four habitats in Sirsi Taluka—Betta land, areca nut plantation, urban garden, and natural forest. Morphological traits varied widely: tree height ranged from 2.43–9 m, GBH from 22–87 cm, bark thickness 0.2–1.45 cm, with bark color from greyish-brown to brownish-gray and blaze from pinkish-red to pale orange. Leaves measured 13.7–26.2 cm in length and 3.5–6.2 cm in width, with leaflet shapes mostly lanceolate (65%) and ob-lanceolate (35%). Diversity was highest in natural forests, followed by Betta land, plantations, and lowest in urban gardens. Soil microbial analysis revealed bacterial and fungal populations were richest in natural forests, moderate in Betta land and plantations, and lowest in urban gardens. Overall, morphological variation and microbial diversity were strongly correlated, decreasing from natural forests to urban gardens.

Keywords: *Saraca asoca*; Western Ghats; Microbial flora; Medicinal tree

Introduction

Saraca asoca (Roxb.) Wild, a small perennial evergreen important medicinal tree from the family Fabaceae (sub family – Caesalpiniaceae), locally known as the Ashoka tree or Seeta Ashoka (Upadhya et al., 2010). The species is native to the central regions of the Deccan Plateau and the mid-altitudinal zones of the Western Ghats in India, as well as Sri Lanka. Ashoka trees have been reported to exhibit notable morphological variation within the Maharashtra region. Soil is one of the most valuable natural resources, harboring diverse assemblages of living organisms. Microorganisms within the soil play a dominant role in decomposition processes and in the cycling of nutrients. The relationship between microbial diversity and soil functionality was well known. Healthy soil serves as a critical habitat, influencing the germination, growth, chemical composition, and overall development of plant species (Bardgett and Shine,1999). Hence, this study was carried out to understand morphological variation and, soil microbial diversity under different growing conditions of *S. asoca* in Sirsi Region

Materials and Methods

The study was conducted across four distinct growing habitats viz., Natural forest, Betta land (privately owned forest land), Areca nut plantation, Urban area (gardens) in Sirsi region of Uttara Kannada district, Karnataka, India to evaluate the morphological parameters and soil microbial dynamics associated with *S. asoca* tree.

Total five individual *S. asoca* were selected from each habitat type for morphological assessment. Following morphological parameters growth parameter (Girth at Breast Height - GBH), bark parameters (bark thickness, colour and blaze colour), leaf parameters (leaf length and width and leaflets shape), ppresence or absence during the study period were carried out as per standard method (Deepika, 2016).

Assessment of Microbial Dynamics

Three composite soil samples were collected from each habitat and bulked into one, yielding fifteen samples across five sites. Microbial assessment was done using the spread plate technique: Martin's Rose Bengal Agar (MRBA) for fungi and Nutrient Agar (NA) for bacteria. After incubation, plates with 30–300 colonies were selected for counting, and results were expressed as Colony Forming Units (CFU) per gram of soil (Bagyaraj et al., 2011).

$$\text{No.of Microbe per mL/gram of Soil} = \frac{N0.\,of\ colonies}{weight\ of\ the\ soil\ in \frac{grams}{Volume}\ of\ liquid\ in\ ml} \times \text{Dilution Factor}$$

Results and Discussion

The qualitative morphological characters of *S. asoca* were presented in table 1 and the qualitative parameters were discussed in running text in this section.

Table 1. Qualitative morphological characters of S. asoca in different growing habitat

Growth Parameters	**Natural Population**	**Betta Land**	**Areca nut Plantation**	**Urban Area**
Tree height (m)	3.00 - 9.00	3.20 - 6.51	2.43 - 4.57	6.00 - 3.00
Girth at Breast height (cm)	34.59 - 87.00	24.38 - 65.29	14.00 - 28.50	22.50 - 85.35

Bark thickness (cm)	0.40 - 1.40	0.40 - 1.20	0.20 - 0.40	0.20 – 1.00
Leaflet length (cm)	13.60 - 21.60	14.20 – 19.00	13.70 – 18.00	15.00 - 26.20
Leaflet length (cm)	3.90 - 5.50	3.90 - 6.20	3.5 - 4.9	4.20 - 5.80

Table 1 indicates higher growth parameters in the natural population for tree height, GBH, bark thickness, leaflet length, and leaflet width, followed by urban areas and Betta land. However, the Areca nut plantation containing *S. asoca* individuals showed poor growth parameters due to regular pruning activities carried out by farmers. The parameters recorded in the present study were consistent with those reported by Paranthaman et al. (2015) and other floras, which document comparable growth characteristics.

The qualitative traits of *S. asoca* - bark, blaze color, and leaflet shape—differ across habitats. Urban trees show varied bark shades from greyish-brown to brownish-gray, while natural forest samples are more uniform with greyish-brown bark. Areca nut plantation trees display lighter tones, such as whitish-grey and brown-white patches. Greater color variation in urban areas reflects diverse environmental influences, whereas consistent bark color in natural and Betta land forests indicates stable growth with minimal stress or disturbance.

Bark blaze varied noticeably among the different sources from reddish to yellowish (urban area), pinkish-red, reddish-pink, orange and pinkish-orange (natural). The Areca Nut Plantation displayed more uniform blaze tones dominated by orange and pale orange, whereas Betta land samples showed orange and pale pinkish blazes. The leaflet shape varies from lanceolate to oblanceolate in the study sites. The study indicates the variation in qualitative and quantitative growth parameters in the study area within the different growing habitats of Ashoka tree (Devan and Warrier, 2021).

Soil Microbial Population Assessment

The microbial counts recorded were represented in table 2. Among microbes, the bacterial population was observed to be highest in natural forest (78.47x105 and 70.83x106 cfu/ g of soil) followed by Betta land. The fungal diversity is highest in natural forest (64.93x104 and 57.63x105 cfu/ g of soil) followed by Betta land and areca nut plantations. The study also indicated the lowest bacterial populations' 19.18x105 and 24.49 x106 cfu/g of soil and fungi 24.79x104 and 22.43x105 cfu/g of soil microbial population in urban gardens. Morphological variations and microbial diversity are correlated with each other from natural forest to urban gardens. These variation among different habitat is observed by the researchers (Bagyaraj et al., 2011).

Table 2. Soil microbial population in different growing conditions of S. asoca

Microbe	**Dilutions**	**Natural forest***	**Betta land***	**Areca nut plantation***	**Urban areas***
Bacteria	10^{-5}	78.47×10^{5}	44.68×10^{5}	31.67×10^{5}	19.18×10^{5}
	10^{-6}	70.83×10^{6}	32.12×10^{6}	29.39×10^{5}	24.49×10^{6}
Fungi	10^{-4}	64.93×10^{4}	36.50×10^{4}	23.97×10^{4}	24.79×10^{4}
	10^{-5}	57.63×10^{5}	29.78×10^{5}	24.84×10^{5}	22.43×10^{5}

** Values were indicated as cfu/ g of soil*

Conclusion

The morphometric study of *S. asoca* revealed site-specific variations influenced by plant physiology and habitat factors, with rainfall and temperature being key drivers. Microbial diversity was also high, linked to organic matter availability across habitats. Forest soils, enriched with leaf litter, supported greater bacterial density, highlighting the role of microbial activity in enhancing plant growth.

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Agricultural Biotechnology: Molecular Innovations, Regulatory Complexities, and Climate-Resilient Crop Improvement

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Abstract

By combining molecular genetics, genome editing, synthetic biology, and computational analytics to increase resilience and productivity, agricultural biotechnology has become a key component of contemporary crop improvement. Traditional breeding methods by themselves are not enough to guarantee sustainable agricultural systems as climate variability increases and the world's food demand rises. Recombinant DNA technology, CRISPR-based genome editing, RNA interference, genomic selection, synthetic biology, and microbial biotechnology are all critically assessed in this review, which also looks at the socioeconomic, ethical, and regulatory factors that affect adoption. With the help of recent developments in genome engineering and systems biology, emphasis is placed on precision breeding, biofortification, and climate resilience. Equal access, balanced governance, and science-based regulatory frameworks are essential to agricultural biotechnology's long-term viability.

Keywords: biofortification, biosafety, climate resilience, CRISPR, genome editing, RNA interference, synthetic biology.

Introduction

Climate change, land degradation, and growing population pressure present previously unheard-of challenges for global agriculture. According to projections, food production will need to increase significantly in order to support almost ten billion people by the middle of the century. However, global crop productivity is threatened by rising temperatures, unpredictable precipitation, salinity intrusion, and emerging pathogens. Despite its historical success, conventional breeding is limited by its limited genetic variability and lengthy generation cycles (Raza et al., 2024). To get around these limitations, agricultural biotechnology provides quick and accurate solutions. It is possible to directly introduce or alter desired traits at the genomic level through molecular interventions. In plant science, the shift from phenotypic selection to genotype-driven improvement represents a fundamental paradigm change. The transformative potential of biotechnology is highlighted by recent developments in computational breeding platforms, multi-omics integration, and genome engineering (R. Zhang et al., 2022).

Recombinant DNA Technology and Transgenic Crops

• Foundations of Genetic Engineering

The foundation for contemporary agricultural biotechnology was established by recombinant DNA (rDNA) technology. Certain genes can be introduced into plant genomes to confer novel traits through particle bombardment and transformation mediated by Agrobacterium tumefaciens. This method made it possible to create genetically modified (GM) crops with enhanced nutritional profiles, herbicide tolerance, and insect resistance (Lombardo et al., 2016).

• Agronomic and Economic Impact

In cotton and maize, Bt crops modified with Bacillus thuringiensis toxin genes greatly decreased the use of chemical insecticides and improved yield stability. Herbicide-tolerant crops facilitated conservation tillage techniques and streamlined weed control systems (Abbas, 2018). In order to address micronutrient deficiencies, biofortification programs like Golden rice increased the provitamin A content. These illustrations show how biotechnology can combine agronomic performance with public health goals (Dubock, 2017).

• Ecological and Regulatory Concerns

Transgenic crops have sparked ethical and ecological discussions despite their quantifiable advantages. Potential gene flow to wild relatives, the emergence of pest population resistance, and the effects on biodiversity are among the issues (Ricroch et al., 2018). Globally, regulatory frameworks differ; some countries adopt more permissive systems, while the European Union maintains precautionary approaches. These differences are a reflection of socio-political factors that go beyond risk assessments that are solely based on science (König, 2002).

Genome Editing: Precision Agriculture in the Molecular Era

• CRISPR-Cas Systems

A significant development in plant biotechnology is the creation of CRISPR-Cas genome editing. Targeted gene insertions and deletions are made possible by CRISPR-Cas9 with previously unheard-of efficiency (D. Zhang et al., 2020). Genome editing, in contrast to transgenic methods, can change endogenous genes without adding foreign DNA, which may change regulatory classification. Applications of CRISPR include the development of disease resistance, increased stress tolerance, and yield improvement. Gao highlights that rapid trait stacking and de novo domestication of wild species are made possible by genome engineering, which is essential to agricultural innovation in the future (Erdoğan et al., 2023).

- **Base Editing and Prime Editing**

Base editing and other second-generation genome editing techniques enable single-nucleotide substitutions without causing double-strand DNA breaks. By allowing targeted insertions and deletions, prime editing further improves accuracy. These technologies increase the extent of trait modification while reducing unwanted genomic changes (Kantor et al., 2020).

- **Climate-Resilient Crop Development**

Climate adaptation strategies are increasingly using genome editing. The role of biotechnology in environmental resilience is demonstrated by changes in genes linked to nitrogen-use efficiency, ion transporters controlling salinity tolerance, and transcription factors controlling drought response (Karavolias et al., 2021). When compared to traditional hybridization techniques, such interventions speed up breeding cycles.

- **Limitations and Intellectual Property Issues**

Not with standing its accuracy, CRISPR technology has drawbacks such as delivery restrictions and off-target effects. Commercialization processes are further complicated by intellectual property disputes pertaining to CRISPR patents. Global adoption trends are still being shaped by the regulatory ambiguity surrounding gene-edited crops (Basit et al., 2026).

Marker-Assisted Selection and Genomic Prediction

To speed up breeding, marker-assisted selection (MAS) incorporates molecular markers like single nucleotide polymorphisms (SNPs) and simple sequence repeats (SSRs). Breeders can find desirable traits early in plant development by connecting markers to quantitative trait loci (QTLs) (Gao & Li, 2025). Using genome-wide marker data and predictive modelling to estimate breeding values, genomic selection advances this idea. Large-scale genomic prediction programs have been made possible by the decrease in genotyping costs brought about by high-throughput sequencing technologies. But in developing nations, computational know-how and technological infrastructure continue to be barriers (Thomson, 2014).

RNA Interference and Crop Protection

Sequence-specific gene silencing at the post-transcriptional level is how RNA interference (RNAi) works. Through host-induced gene silencing, RNA interference (RNAi) has been used in agriculture to improve viral resistance and reduce insect pests (Filipowicz et al., 2005). By providing non-transgenic pest management options, spray-induced gene silencing lessens the need for chemical pesticides. Although promising, RNAi technologies have issues with cost, delivery efficiency, and environmental stability (Chen et al., 2025).

Synthetic Biology and Metabolic Engineering

By reimagining biological systems, synthetic biology goes beyond gene editing. Improved carbon absorption, more effective use of nutrients, and the production of useful metabolites are all made possible by engineering metabolic pathways (Pixley et al., 2019). For instance, the micronutrient content of staple crops is enhanced by biofortification via targeted metabolic engineering. These developments demonstrate how plant molecular biology and computational modelling intersect. However, philosophical questions about long-term ecological effects and human manipulation of natural systems are brought up by synthetic biology (Prusinkiewicz & Runions, 2012).

Microbial Biotechnology and Sustainable Soil Systems

By improving soil fertility and nutrient cycling, microbial biotechnology enhances plant genetic interventions. Plant growth-promoting rhizobacteria (PGPR) increase stress tolerance and promote the synthesis of phytohormones (Ipek et al., 2014). While nitrogen-fixing bacteria lessen reliance on synthetic fertilizers, mycorrhizal associations improve phosphorus uptake. The development of targeted microbial inoculants is made easier by the characterization of soil microbial communities made possible by advances in metagenomics. However, the need for location-specific microbial formulations is highlighted by variations in field performance (Liu-Xu et al., 2024).

Multi-Omics Integration and Systems Biology

Comprehensive analysis of plant responses to environmental stress is made possible by the integration of genomics, transcriptomics, proteomics, and metabolomics. By simulating gene regulatory networks, systems biology increases the precision of predictive breeding (Satrio et al., 2024). In order to support precision agriculture initiatives, artificial intelligence platforms are increasingly analysing large omics datasets. Biotechnology is at the forefront of innovation in digital agriculture thanks to this interdisciplinary convergence (Pant & Kumari, 2026).

Regulatory, Ethical, and Socio-Economic Dimensions

Frameworks for risk assessment look at environmental interactions, gene stability, toxicity, and allergenicity. Different international policies have an impact on the dynamics of trade, investment, and research. Adoption of biotechnology is still heavily influenced by public opinion, which is frequently influenced by false information and a lack of scientific literacy (Sturgis et al., 2005). Seed sovereignty, intellectual property rights, and fair access to technology are examples of ethical issues. Transparent governance and inclusive stakeholder engagement are necessary for sustainable implementation (Tumpa & Naeni, 2025).

Future Directions

Agricultural biotechnology in the future will probably prioritize:

- De novo domestication of underutilized crops (Gasparini et al., 2021)
- Increased efficiency of nitrogen fixation (Lindström & Mousavi, 2020)
- Predictive breeding powered by AI (Cai et al., 2025)
- Increased methods of biofortification (Ofori et al., 2022)
- Translating laboratory innovations into field applications will require interdisciplinary collaboration (Ioachimescu & Shaker, 2025).

Conclusion

Modern agriculture is being revolutionized by agricultural biotechnology. Molecular innovations, such as synthetic biology, CRISPR-mediated precision editing, and recombinant DNA technology, provide workable answers to the problems of climate resilience and food security. However, for adoption to be sustained, responsible governance, fair distribution, and science-based regulation are essential. The future of resilient food systems will be shaped by the integration of digital agriculture, systems biology, and biotechnology as environmental pressures increase.

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Agricultural Biotechnology

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Abstract

Agricultural biotechnology is an integrative scientific domain that draws on disciplines such as molecular biology, genetics, microbiology, biochemistry, and bioinformatics to boost farm productivity while promoting sustainability. The pressures of a growing global population, shifting climate patterns, declining soil health, and shrinking natural resources have heightened the need for advanced and efficient agricultural innovations. Although traditional breeding techniques continue to be useful, they are often slow and lack accuracy. Modern biotechnological methods, on the other hand, offer precise solutions through tools like tissue culture, recombinant DNA techniques, genome editing, molecular markers, omics-based approaches, and the use of beneficial microbes for crop enhancement.

The identification of the DNA double helix by James Watson and Francis Crick laid the foundation for understanding genetic inheritance at the molecular level. Building on this knowledge, genome editing innovations developed by Jennifer Doudna and Emmanuelle Charpentier have made it possible to accurately modify plant DNA. Genetically engineered crops, including Bt cotton, exhibit improved resistance to pests and higher productivity. In India, regulatory oversight of such technologies is managed by the Genetic Engineering Appraisal Committee, while global recommendations are guided by the Food and Agriculture Organization.

In addition, microbial biotechnology supports sustainable farming through the application of biofertilizers, plant growth–promoting microorganisms, and environmentally friendly pest control methods. New and rapidly advancing fields such as synthetic biology, nanobiotechnology, and integrated omics approaches are further broadening the possibilities for precision agriculture and crop improvement. Nevertheless, the adoption of these technologies must be carried out with careful consideration of biosafety regulations, intellectual property issues, ethical questions, and broader social impacts. Overall, agricultural biotechnology is a key driver in ensuring food security, protecting the environment, and fostering sustainable agricultural progress.

Keywords: Genetic Engineering; CRISPR–Cas; Molecular Breeding; Biofertilizers; Sustainable Agriculture

Introduction

Agricultural Biotechnology

Agricultural biotechnology involves using advanced biological knowledge and molecular tools to enhance plants, animals, and microorganisms for farming needs. It integrates concepts from genetics, molecular biology, microbiology, biochemistry, and bioinformatics to create crops that produce higher yields, offer improved quality, and show greater tolerance to environmental and biological stresses.

The groundwork for contemporary biotechnology was laid with the identification of the DNA double-helix structure by James Watson and Francis Crick in 1953, which explained how genetic information is stored and passed on. In the following decades, especially during the 1970s, the development of recombinant DNA methods made it possible to move selected genes between different species, initiating the era of genetic engineering in agriculture.

The field of agricultural biotechnology has grown extensively and now spans a wide range of techniques and disciplines, including plant tissue culture, genetic modification, genome editing, molecular breeding, microbial applications, omics-based approaches, synthetic biology, and the use of nanotechnology.

Today, it emphasizes increasing productivity in a sustainable manner, strengthening crops against climate-related challenges, enhancing nutritional value, and lowering reliance on chemical fertilizers and pesticides. This area of science is vital for maintaining food availability, supporting farmers' livelihoods, and promoting the responsible use of natural resources.

Plant Tissue Culture and Micropropagation

Plant tissue culture refers to the practice of cultivating plant cells, tissues, or entire organs in a controlled, sterile environment using a specially prepared nutrient medium. This method relies on the concept of totipotency, which means that each plant cell possesses the inherent ability to develop into a whole plant when supplied with suitable nutrients and environmental conditions.

Major Techniques

Callus Culture

Callus refers to a loosely arranged cluster of plant cells that develops from explants like leaves, stems, or roots when they are grown on a culture medium enriched with particular growth regulators. This type of culture is widely utilized in genetic modification work, the study of somaclonal variation, and the production of valuable secondary metabolites.

Somatic Embryogenesis

This method refers to the formation of embryo-like structures from somatic, or non-reproductive, cells. These structures are capable of growing into fully developed plants and are commonly used for mass propagation as well as the creation of artificial seeds.

Organogenesis

Organogenesis refers to the formation of shoots and roots from cultured tissues. It is commonly used for plant regeneration after transformation experiment

Micropropagation

Micropropagation is a technique used to quickly produce large numbers of identical plants through in vitro culture methods. This approach helps generate planting material that is both free from diseases and genetically consistent.

Applications

PTC is widely used in banana, sugarcane, potato, orchids, and ornamental crops. It is also valuable for germplasm conservation, haploid production, embryo rescue, and production of medicinal compounds.

Genetic Engineering in Crop Improvement

Genetic engineering refers to the deliberate alteration of an organism’s genetic material by adding, removing, or changing particular genes. This approach relies on recombinant DNA methods to insert beneficial traits into plants.

Process of Genetic Engineering

- Locating and extracting the desired gene from the source organism.
- Integrating this gene into an appropriate carrier or vector.
- Introducing the gene into plant cells.
- Identifying successfully modified cells and regenerating them into whole plants.
- Conducting field trials along with safety and regulatory evaluations.

Methods of Gene Transfer

- **Agrobacterium-Mediated Approach:** Makes use of the natural DNA transfer capability of Agrobacterium tumefaciens.
- **Biolistic or Gene Gun Technique:** Propels microscopic particles coated with DNA into plant cells.
- **Electroporation:** Applies electrical pulses to create temporary pores in cell membranes, allowing DNA entry.

A well-known example is Bt cotton, developed by incorporating genes from Bacillus thuringiensis, which help protect the crop from insect damage. Through such techniques, genetic engineering has also enabled traits like tolerance to herbicides, extended shelf life of fruits, and improved nutritional quality.

CRISPR–Cas Genome Editing in Agriculture

CRISPR–Cas represents a modern genome editing approach that allows highly accurate changes to specific regions of DNA. It works by using a guide RNA to lead the Cas enzyme to a chosen gene, where it creates a break in the DNA, enabling the addition, removal, or alteration of genetic sequences.

The introduction of CRISPR–Cas9 technology by Jennifer Doudna and Emmanuelle Charpentier has brought a major transformation to the field of plant biotechnology.

Applications

- Creation of crop varieties with increased productivity
- Strengthening tolerance to stresses such as drought and high salinity
- Improving resistance to pathogens including viruses, fungi, and bacteria
- Increasing the nutritional value of crops

Compared to traditional breeding methods, CRISPR technology offers greater accuracy and speed. In many cases, it can modify genes without introducing external DNA, which may make it more favorable within existing regulatory guidelines.

Marker-Assisted Selection (MAS) and Molecular Breeding

Marker-assisted selection (MAS) is a breeding approach that employs DNA markers associated with particular traits to guide the selection process. This technique enables the identification of plants carrying desired genes at an early stage, without waiting for the traits to appear physically.

Types of DNA Markers

- RAPD (Random Amplified Polymorphic DNA)
- AFLP (Amplified Fragment Length Polymorphism)
- SSR (Simple Sequence Repeats)
- SNP (Single Nucleotide Polymorphism)

MAS enhances the efficiency of breeding programs, shortens development time, and facilitates the combination of multiple traits, such as higher yield and disease resistance, into a single plant. It is widely applied in crops like rice, wheat, maize, and various pulses.

Transgenic Crops and Biosafety Regulations

Transgenic crops are plants that contain foreign genes introduced through genetic engineering. Before commercialization, they undergo rigorous biosafety testing to evaluate environmental and human health risks. Risk Assessment Includes 1. Allergenicity testing 2. Toxicity studies 3. Environmental impact analysis 4. Gene flow evaluation

In India, the oversight and approval of genetically engineered products are handled by the Genetic Engineering Appraisal Committee. On a global level, frameworks and guidelines are provided by organizations such as the Food and Agriculture Organization and under the Cartagena Protocol on Biosafety. Effective regulation helps guarantee the safe application of biotechnology and fosters public trust.

Biofertilizers and Plant Growth-Promoting Microorganisms

Biofertilizers are formulations containing beneficial microorganisms that enhance nutrient availability and plant growth.

Types

1. Nitrogen-fixing bacteria (Rhizobium, Azotobacter)
2. Phosphate-solubilizing microorganisms
3. Silicate-solubilizing microorganisms
4. Mycorrhizal fungi

Plant growth-promoting microorganisms (PGPM) also produce growth hormones, suppress pathogens, and improve root architecture. These sustainable alternatives reduce chemical fertilizer dependency and improve soil health

Agricultural Microbial Biotechnology

Agricultural microbial biotechnology focuses on industrial-scale production of beneficial microbes used in agriculture.

Products Include

- Bioinoculants
- Biopesticides
- Biodegradation agents

Fermentation technology is used for mass multiplication of microorganisms. Carrier-based and liquid formulations enhance stability and field performance. Microbial consortia are increasingly used for integrated nutrient and pest management.

Biotechnology in Managing Abiotic Stress

Environmental factors like drought, high salinity, extreme temperatures, and cold conditions can significantly lower crop yields. Biotechnology helps address these challenges by identifying genes and regulatory mechanisms that enable plants to respond and adapt to such stresses.

Strategies

- Overexpression of stress-tolerant genes
- Genome editing for stress adaptation
- Molecular breeding for stress resistance

These approaches improve production of osmoprotectants, antioxidants, and stress proteins, enhancing plant survival under adverse conditions.

Biotechnology in Plant Disease Management

Biotechnology offers advanced methods that enable the timely identification and effective control of plant diseases.

Key Approaches

- PCR-based molecular diagnostics
- RNA interference (RNAi) is a technique used to suppress gene expression by inhibiting specific genetic activity.
- Resistance gene pyramiding
- Biocontrol agents such as Trichoderma

These methods reduce chemical pesticide use and support eco-friendly disease management.

Synthetic Biology in Crop Science

Synthetic biology involves redesigning biological pathways to create improved traits. It enables modification of metabolic pathways for enhanced nutrient content, improved photosynthesis, and production of high-value compounds. Synthetic gene circuits can regulate plant growth and stress responses more efficiently.

Nanobiotechnology in Agriculture

Nanobiotechnology uses nanoscale materials for agricultural applications. Nano-fertilizers and nano-pesticides allow controlled release and targeted delivery, improving nutrient efficiency and reducing environmental pollution. Smart nanocarriers enhance crop productivity with minimal input use.

Biotechnology in Horticultural Crops

Biotechnological approaches help enhance desirable attributes in fruits and vegetables, including their appearance, flavor, nutrient content, and storage longevity. Tissue culture techniques enable the generation of healthy, disease-free planting stock. In addition, methods such as genetic modification and molecular breeding strengthen the ability of horticultural crops to withstand pests and challenging environmental conditions.

Intellectual Property Rights (IPR) and Patent Issues

IPR protects innovations in agricultural biotechnology. Plant breeders' rights and patents provide legal protection for new varieties and technologies. Agreements such as TRIPS regulate global intellectual property systems. Balanced policies are necessary to encourage innovation while protecting farmers' rights.

Ethical, Environmental and Socioeconomic Issues

Ethical concerns include loss of biodiversity, gene flow to wild relatives, seed sovereignty, and corporate control over agricultural resources. Environmental risks must be carefully assessed before commercialization. Public awareness, transparent research practices, and strong regulatory systems are essential for responsible adoption.

Future Prospects and Sustainable Agriculture

The future of agricultural biotechnology lies in integration of genome editing, artificial intelligence, digital agriculture, and climate-smart farming practices. Emphasis will be placed on sustainable intensification, nutritional security, reduced environmental impact, and resilience to climate change. Responsible innovation, inclusive policies, and international cooperation will ensure that biotechnology contributes effectively to global food security and sustainable agricultural development.

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Molecular Biology and Genetics of *Murdannia species*

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Abstract

Murdannia Royle (Commelinaceae) is a morphologically diverse genus comprising around 50–60 species distributed across tropical and subtropical regions of Asia, Africa, and the Americas. Recent cytogenetic, molecular, and phylogenomic studies have begun to unravel the genome-level variation and evolutionary patterns underpinning this genus. This chapter synthesizes current knowledge on the molecular biology and genetics of *Murdannia* species, focusing on chromosome numbers, karyotype asymmetry, nuclear DNA content, and the use of molecular markers (e.g., ISSR, cpDNA, next-generation sequencing) to infer phylogeny, population structure, and speciation history. Evidence indicates that polyploidy and karyotypic rearrangements are central to *Murdannia* diversification, with several taxa exhibiting widespread aneuploidy and genome-size variation. The chapter also highlights research gaps and prospects for applying modern genomics and functional-molecular tools to better understand adaptation, conservation, and potential medicinal applications in *Murdannia*.

Introduction

Murdannia, a genus in the family Commelinaceae, includes herbaceous perennials and annuals characterized by fleshy stems, alternate leaves, and often showy flowers. The genus is distributed from India and Southeast Asia through China, Japan, and into Africa and the Neotropics, with over 50 species reported worldwide and about 25–27 taxa occurring in India alone. Many species are adapted to open, disturbed, or seasonally moist habitats, and several are used in traditional medicine or as ornamentals.[1][2][3][4]

Despite their taxonomic and ecological relevance, molecular-genetic studies on *Murdannia* have been relatively sparse compared with other monocot genera.

Nevertheless, recent cytogenetic, flow-cytometric, and phylogenomic publications provide a solid foundation for discussing the molecular biology and population genetics of the genus.[5][6][7]

Chromosome Numbers and Ploidy

Cytogenetic work on *Murdannia* has revealed a wide range of diploid chromosome numbers and multiple ploidy levels. Across several Asian species, 2n values include 18, 20, 22, 24, and 60, indicating frequent polyploidization and aneuploidy. For example, *M. edulis and M. spectabilis* show 2n = 20, while *M. loriformis* has 2n = 18 and *M. madica* and *M. nudiflora* have 2n = 22. Some studies also report tetraploid and higher-ploidy cytotypes in *M. nudiflora* and related taxa, suggesting that genome duplication has played a significant role in speciation and adaptation.[6][7][5]

In Indian endemic species, Kaur et al. report that *M. assamica* and *M. striatipetala* share the haploid number n = 10 (2n = 20), whereas *M. fadeniana* has n = 20 (2n = 40), implying an autotetraploid origin from a diploid with x = 10. This reinforces the view that the basic number x = 10 is ancestral in the genus, with both polyploidy and aneuploidy contributing to cytological diversity.[7][6]

Karyotype and Nuclear Genome Size

Karyomorphological analyses show substantial variation in chromosome asymmetry and total chromosome length among *Murdannia* species. The karyotype formula (e.g., 8m + 1sm + 1st in *M. assamica* and 20m in *M. fadeniana*) reflects differing degrees of centromere position and arm-length heterogeneity. Indices such as asymmetry coefficients (A1, A2), total form percentage (TF%), and asymmetry index (As K%) indicate that M. assamica has the most asymmetric complement, whereas *M. fadeniana* shows the most symmetrical karyotype among the three species studied.[6]

Flow-cytometric and image-cytometric studies of nuclear DNA content in several Commelinaceae, including *Murdannia*, reveal large interspecific variation in 2C values, spanning roughly two orders of magnitude (approximately 0.3–33 pg per nucleus). This extensive range suggests repeated genome-size change and possible differential amplification of repetitive DNA over evolutionary time. Such variation underpins the utility of chromosome and genome-size data as tools for delimiting species and reconstructing evolutionary pathways in the genus.[5][7][6]

Molecular Markers and Genetic Diversity

Modern plant genetics increasingly relies on molecular markers to assess genetic diversity, population structure, and phylogenetic relationships. In *Murdannia*, studies have begun to employ markers such as ISSR (inter-simple sequence repeats), AFLP (amplified fragment length polymorphisms), and chloroplast DNA (cpDNA) sequences, although the coverage remains limited compared with crop or model species.[8][9]

ISSR and AFLP markers are particularly useful for detecting polymorphisms at multiple loci without prior genome-sequence information. They have been applied broadly in plant systematics to quantify genetic differentiation, reconstruct genealogical relationships, and identify cryptic species or hybrids. In the context of *Murdannia*, similar marker systems could be used to compare closely related taxa (e.g., *M. nudiflora, M. semiteres, M. gigantea*) and test hypotheses of hybridization, introgression, or allopatric speciation.[10][8]

Microsatellite and sequence-based markers (e.g., nrDNA ITS, trnL–F, rbcL) are also promising for intrageneric phylogeny reconstruction. Chloroplast SSRs and complete cp genomes have proven highly informative for resolving low-level relationships in other monocots, and their adaptation to *Murdannia* would likely clarify species boundaries and biogeographic history.[11][9]

Phylogenomics, Biogeography, and Speciation

Murdannia belongs to Commelinaceae, a monocot family in the order Commelinales, whose phylogenomic structure has been recently clarified using hundreds of nuclear and plastid loci. These large-scale phylogenies confirm that Commelinaceae are strongly supported as a monophyletic group, with *Murdannia* forming a distinct clade alongside genera such as Aneilema and Pollia.[12][13]

For *Murdannia* itself, taxonomic revisions and phylogenetic work emphasize that polyploidy and chromosomal rearrangements have been more important than autopolyploidy alone in speciation. Allopolyploidization, aneuploid chromosome loss or gain, and karyotype reshuffling appear to have driven reproductive isolation and niche differentiation in several lineages.[7][6]

Biogeographic patterns suggest multiple dispersal and vicariance events across Asia and beyond. Indian and Southeast Asian *Murdannia* taxa form a core of diversity, with some species (e.g., *M. nudiflora*) occurring in both Asia and Africa, raising questions about long-distance dispersal versus ancient vicariance. Molecular dating combined with chloroplast and nuclear sequence data could help distinguish between these scenarios and refine the temporal framework of *Murdannia* radiation.[14][1][12][11]

Linking Molecular Biology to Functional Traits and Medicinal Use

Parallel research on *Murdannia* chemistry shows that several species accumulate bioactive metabolites, including flavonoids, phenolic acids, and terpenoids, which contribute to reported antioxidant, anti-inflammatory, and antidiabetic properties. Although most pharmacological studies remain phenotypic or biochemical, there is growing interest in linking genetic variation to secondary-metabolite profiles.[2]

Functional-molecular approaches such as transcriptomics and gene expression profiling could, for example, identify key genes involved in flavonoid biosynthesis or stress-response pathways in *M. nudiflora* or *M. gigantea*. Comparative studies across cytotypes (diploids vs. polyploids) might also reveal how genome duplication and karyotype asymmetry influence metabolic diversity and ecological performance. Such work would bridge classical cytogenetics with molecular-trait mapping and provide a stronger basis for breeding and biotechnological applications.[8][6][7]

Future Directions and Research Gaps

Several key areas remain underexplored for the molecular biology and genetics of Murdannia:

- **Genome-Scale Data:** No reference genome has yet been published for any Murdannia species. High-throughput sequencing (e.g., whole-genome or transcriptome sequencing) would enable the development of SNP markers, gene annotation, and comparative genomics with related Commelinaceae.[9][12]
- **Population Genetics:** Fine-scale population-genetic studies using SSRs or SNPs are needed to quantify gene flow, local adaptation, and inbreeding across fragmented habitats.[8]
- **Phylogeography:** Integrating cpDNA and nuclear sequence data with ecological niche modeling would help reconstruct post-glacial and recent dispersal histories, particularly in the Indian and Southeast Asian floras.[11][9]
- **Cytogenetic–Molecular Integration:** Combining chromosome painting, banding patterns, and molecular markers could clarify the role of specific chromosomal rearrangements in speciation and adaptation.[15][6]

Addressing these gaps will require coordinated efforts across cytology, molecular biology, ecology, and bioinformatics, especially in under-documented regions of India and Southeast Asia where *Murdannia* diversity is high.[3][4][1]

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DNA Replication in Prokaryotes and Eukaryotes – A Comparative Analysis

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Abstract

DNA replication is a crucial biological procedure that ensures the precise copying of genetic material prior to cell division. This process guarantees the transfer of genetic information from one generation to the next. While the overall mechanism of DNA replication is similar across all life forms, significant differences can be observed between prokaryotic and eukaryotic systems, largely due to variations in the structure of the genome, cellular organization, and the enzymes involved. The DNA replication process operates on a semi-conservative model, where each daughter DNA molecule consists of one strand from the parent and one newly formed strand. In prokaryotes, DNA replication generally initiates at a single origin and utilizes a relatively straightforward set of enzymes, whereas eukaryotic replication is more intricate because of larger genomes, linear chromosomes, and multiple sites of replication. This chapter describes the basic principles of DNA replication and provides a comparative analysis of replication mechanisms in prokaryotic and eukaryotic organisms.

Keywords: DNA replication, Replication fork, DNA polymerase.

Introduction

The process of creating two identical copies of DNA is known as DNA replication. It is essential for life as it ensures the accurate transmission of genetic information from one generation to the next. DNA replication in prokaryotic and eukaryotic organisms differs due to variations in genome complexity, replication machinery, and regulatory mechanisms. Prokaryotic organisms generally possess a single circular chromosome and replicate their DNA using a relatively simple system. In contrast, eukaryotic organisms contain multiple linear chromosomes and require more complex regulatory mechanisms and numerous replication proteins (DePamphilis, 1993; O'Donnell et al., 2013; Hu & Stillman, 2023).

The mechanism of DNA replication was first clarified through the experiment of Meselson and Stahl in 1958. Using nitrogen isotope labeling in *E.coli*, they showed that DNA replication follows a semi-conservative model, where each daughter DNA molecule contains one parental and one newly synthesized strand (Meselson & Stahl, 1958). Since then, research has revealed the molecular mechanisms and enzymes involved in DNA synthesis.

This chapter describes the basic principles of DNA replication and highlights the similarities and differences between replication in prokaryotic and eukaryotic organisms.

Basics of DNA Replication

Each daughter DNA molecule has one original strand and one newly synthesised strand according to the semi-conservative model of DNA replication. Three potential methods of DNA replication, conservative, semi-conservative, and dispersive replication, were put out prior to this model's validation.

The conservative model states that the parental DNA molecule remains unchanged while a completely new copy is formed. In the semi-conservative model, each parental strand acts as a template for the synthesis of a complementary strand. The dispersive model suggests that parental DNA strands break into fragments and new DNA segments are interspersed within them (Fig. 1).

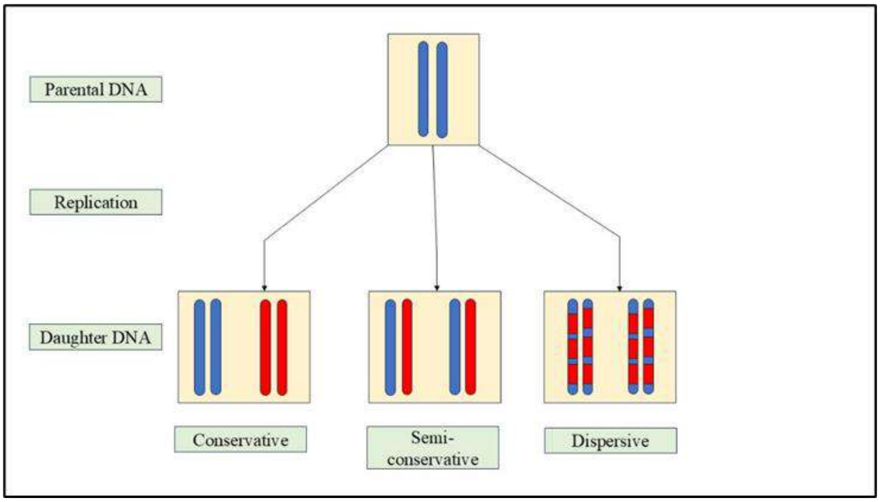

Figure 1: Models of DNA replication.

Key Steps in DNA Replication

- **Initiation**

Origins of replication are specific DNA sequences where replication begins. Proteins bind to the origin and unravel the DNA double helix during this step, creating a replication bubble and replication forks (Costa & Diffley, 2022).

- **Elongation**

Nucleotides complementary to the template strand are added by DNA polymerases in the 5′ → 3′ orientation to create new DNA strands. The two strands are duplicated differently because DNA polymerase can only synthesise DNA in the 5′ → 3′ direction:

- **Leading Strand:** Continuously synthesized
- **Lagging strand:** produced irregularly as brief sections known as Okazaki fragments. DNA ligase then joins these pieces to create a continuous DNA strand (Balakrishnan & Bambara, 2010; Maga et al., 2001) (Fig.2).

- **Termination**

Replication ends when the entire DNA molecule has been copied, and replication complexes detach from the DNA (Costa & Diffley, 2022; Dewar & Walter, 2017).

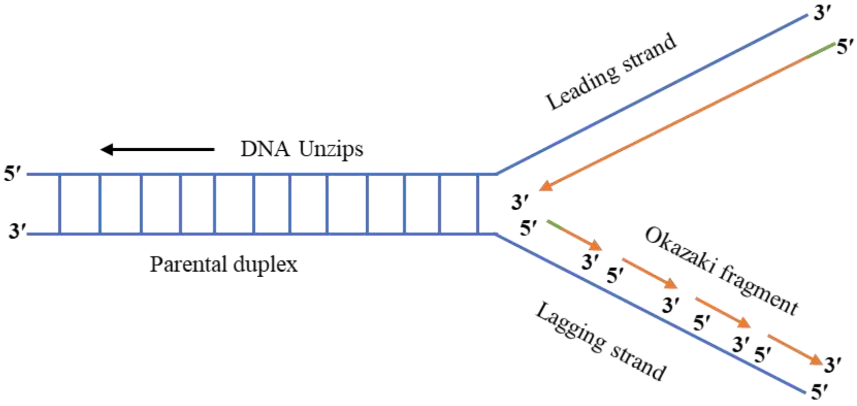

Figure 2: DNA replication fork showing leading and lagging strands.

Prokaryotic DNA Replication

DNA replication usually takes place in prokaryotes during the bacterial cell cycle's C phase. OriC is the single origin where replication starts. OriC is bound by the initiator protein DnaA, which encourages the DNA double helix to unwind. The replication fork is created when the helicase DnaB further unwinds the DNA strands with the help of DnaC.

Several enzymes participate in prokaryotic DNA replication:

- DNA strands are unwound by Helicase.
- Supercoiling strain is relieved by Topoisomerase.
- RNA primers are produced by Primase (DnaG).
- The new DNA strand is created by DNA polymerase III.
- DNA polymerase I: this enzyme substitutes DNA or RNA primers.

- DNA ligase is responsible for joining Okazaki fragments (Messer, 2002; WolaÅ„Ski et al., 2015; O'Donnell et al., 2013) (Fig.3).

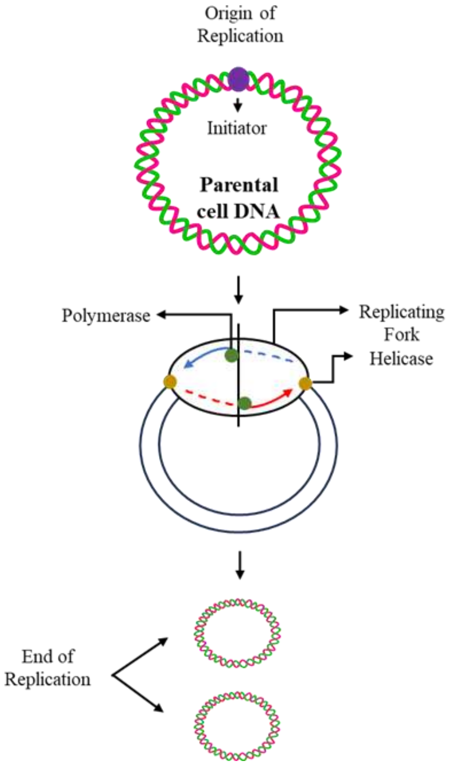

Figure 3. Prokaryotic DNA replication

Eukaryotic DNA Replication

In eukaryotic cells, DNA replication takes place during the cell cycle's S phase. Eukaryotic genomes are bigger and arranged into several linear chromosomes, in contrast to prokaryotes. Autonomously Replicating Sequences (ARS) are regions where replication starts. These sequences are bound by the Origin Recognition Complex (ORC), which then enlists other proteins to create the pre-replication complex.

Key proteins involved include:

- DNA is unwound by the MCM helicase complex.
- RNA-DNA primers are produced by DNA polymerase α.
- DNA polymerase δ is responsible for creating lagging strands.
- The leading strand is created by DNA polymerase ε.
- Single-stranded DNA is stabilised by Replication Protein A (RPA).

A unique feature of eukaryotic replication is the presence of telomeres at chromosome ends. The enzyme telomerase extends telomeres and prevents genetic information loss during DNA replication (O'Donnell et al., 2013; Limas & Cook, 2019; Errico & Costanzo, 2010; Costa & Diffley, 2022; Pfeiffer &

Lingner, 2013). Key differences between prokaryotic and eukaryotic DNA replication are given in Table 1.

Table 1: Comparison of Prokaryotic and Eukaryotic DNA Replication

Feature	**Prokaryotes**	**Eukaryotes**
Genome structure	Circular chromosome	Linear chromosomes
Origin of replication	Single origin	Multiple origins
Replication location	Cytoplasm	Nucleus
Okazaki fragment size	1000–2000 nucleotides	100–200 nucleotides
Replication speed	Faster	Slower
Telomeres	Absent	Present

Future Perspectives

Recent advances in molecular biology and genomics have improved our understanding of DNA replication mechanisms. Techniques such as next-generation sequencing and structural biology have provided insights into replication dynamics. DNA replication plays an important role in medical science, particularly in cancer and genetic diseases. Errors in replication can lead to genomic instability. Future research will focus on identifying regulatory proteins and developing therapeutic strategies targeting replication pathways.

Summary

DNA replication is a tightly regulated process essential for maintaining genetic information. Although the basic principles are similar, prokaryotic and eukaryotic systems differ in genome structure and complexity. Prokaryotic replication is simpler and begins at a single origin, whereas eukaryotic replication involves multiple origins and numerous regulatory proteins. Understanding DNA replication is important for advances in molecular biology, biotechnology, and medicine.

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The Significance of Mutation Breeding in Contemporary Plant Breeding

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Abstract

Mutations are changes in DNA that occur during cell division or replication, creating genetic variation essential for plant breeding. Mutation breeding plays a vital role in agricultural development by generating desirable traits to improve crop yield and quality. With increasing population pressure, ensuring food security has become challenging, making crop improvement more important than ever. Mutations may arise naturally or be induced using physical or chemical mutagens. Historically, naturally occurring mutations contributed to major advances such as semi-dwarf wheat and rice during the Green Revolution. Today, induced mutagenesis is widely used in plant molecular biology to identify and study genes and their functions. Molecular mutation breeding is opening new avenues for crop improvement. In the future, mutation breeding will remain crucial for developing resilient, high-yielding crops and addressing global food security challenges.

Keywords: Crop improvement, Mutagenesis and Molecular mutation breeding.

Introduction

Crop genetic improvement is essential for addressing global food security and nutritional challenges [1]. Rapid population growth, expected to reach 9 billion by 2050, increases pressure on food production systems [2]. Plant breeding depends on genetic variability, and mutations heritable changes in DNA serve as a primary source of new alleles in all species [3]. These variations can occur naturally or be induced using mutagenic agents such as radiation and chemicals to generate desirable traits [4]. Mutation-induced variability drives evolution and provides valuable material for crop improvement through selection.

Advances in molecular genetics and DNA technologies have moved plant breeding, particularly mutation breeding, into a molecular era [5]. Mutations cause heritable phenotypic changes at the gene level, enabling the development of new and improved crop characteristics [6]. Mutation breeding involves inducing such changes to create superior crop varieties with desirable traits like higher yield, stress tolerance, and disease resistance [7].

Recent developments in plant molecular biology, genomics, and reverse genetics have enhanced the precision and efficiency of induced mutagenesis [9]. Breeders can now better identify and utilize beneficial mutations for crop improvement. This chapter focuses on the applications, advantages, and limitations of mutation breeding in modern agriculture.

Types of Mutation Breeding and Mutagenesis

Mutagenesis: The process of creating a mutation that changes an organism's genetic makeup is known as mutagenesis. It can happen spontaneously in nature or as a result of exposure to mutagens. Additionally, it can be tested also be experimentally using laboratory procedures. A mutagen is a mutation causing agent it may be physical or chemical, results in an increased rate of mutations in an organisms' genetic code. Mutagenesis as a science was developed based on work done by Hermann Muller, Charlotte Auerbach &J.M.Robson in the first half of 20th century.

Importance of Mutation in Breeding

Advances in molecular genetics and DNA technologies have transformed plant breeding, especially mutant breeding, into a molecular-driven approach [10]. Molecular mutation breeding enhances efficiency and precision compared to conventional methods [11]. It offers benefits such as higher yield, early maturity, stress and salinity tolerance, waterlogging resistance, and improved seed traits [12]. Successful mutant varieties of wheat, rice, and barley have been developed with improved quality, dwarfism, and disease resistance. Mutation-induced male sterility also supports cost-effective hybrid seed production. Globally, over 2250 mutant varieties have been released, with rice, wheat, and barley contributing significantly [13]. Radiation and chemical mutagens like EMS are widely used for inducing mutations. Induced mutagenesis remains a rapid and cost-effective method for creating new alleles and understanding gene function, supporting future crop improvement and productivity [14].

Conclusion

Mutation breeding is a modern plant breeding technique used to increase genetic variation, develop new varieties, produce haploids, induce male sterility, and improve crop tolerance. Induced mutagenesis is an effective method for creating variation and identifying important genes. It enhances crop traits more quickly than conventional breeding, demonstrating its value as a versatile and efficient approach for crop improvement.

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Mutation Breeding in Coriander: Mutagenic Agents and Application Techniques

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Abstract

A significant spice crop, *Coriandrum sativum* L. (coriander) is grown extensively for its leaves, seeds, and essential oils. Mutation breeding is a useful technique for increasing coriander yield, its quality, and disease resistance. The use of physical and chemical mutagens in coriander breeding, as well as the ensuing genetic variability and enhanced features.

Keywords: *Coriandrum sativum* L., Mutation breeding, Physical and chemical mutagens, genetic variability.

Introduction

The genetic improvement of coriander (*Coriandrum sativum* L.) relies heavily on the presence of genetic variability. When natural variation is limited, mutation breeding serves as a powerful tool to induce novel traits. By employing physical and chemical agents, breeders can disrupt the genetic code to create “hopeful monsters”- variants that may possess superior yield, higher essential oil content, or better disease resistance.

Classification of Mutagenic Agents

Mutagens are broadly categorized into physical and chemical agents. In coriander research, these tools are selected based on their ability to penetrate seed tissues and their efficiency in inducing chromosomal or point mutations.

A. Physical Mutagens (Ionizing Radiation)

Physical mutagens typically involve ionizing radiation, which strips electrons from atoms, leading to DNA strand breaks.

- **Gamma Rays:** These are the most widely used physical mutagens in coriander breeding. Emitted from sources like Cobalt-60 (^ {60} Co), they have high penetrating power.

- **Dosage Dynamics:** Research indicates that the dosage of radiation is critical. For coriander, doses ranging from 10 kR to 25 kR (kilo-Roentgens) are standard.
- **Biological Impact:** While higher doses increase the likelihood of mutation, they often lead to a "biological cost" in the M_1 generation, such as reduced pollen fertility and stunted growth. Moderate doses are generally preferred to balance mutation frequency with plant survival.

Chemical Mutagens

Chemical mutagens are often preferred for inducing point mutations (single nucleotide changes) rather than large-scale chromosomal aberrations.

- **Alkylating Agents:** This group includes Ethyl Methane Sulphonate (EMS) and Methyl Methane Sulphonate (MMS). They work by adding ethyl or methyl groups to DNA bases, leading to mispairing during replication.
- **Sodium Azide (SA):** A potent chemical mutagen known for its high efficiency and low toxicity to the plant's overall physiology. It is frequently used to create variations in seed size and aromatic properties.
- **Comparison:** Some studies suggest that MMS can be particularly effective because it can induce desired mutations at lower concentrations with less biological damage to the embryo compared to harsher chemicals.

Synergy through Combination Treatments

To maximize the “mutation spectrum” – the variety of different types of mutations produced – breeders often employ combination treatments. By exposing coriander seeds to a physical mutagen (like Gamma rays) followed by a chemical one (like EMS), the cumulative effect can increase mutation frequency. This approach aims to hit different parts of the genome or utilize different repair mechanisms within the cell to lock in beneficial traits.

The Relationship between Dose and Response

A fundamental principle in mutation breeding is the inverse relationship between the mutagen dose and plant vitality.

- **Germination and Growth:** As the concentration of a chemical or the intensity of radiation increases, the germination rate typically decreases.
- **Seedling Vigor:** High doses often result in slower seedling growth and higher lethality (the LD_ {50} or Lethal Dose 50% is a common benchmark used to determine the ideal treatment level).
- **Optimal Selection:** The goal is to find the "sweet spot" where the dose is high enough to cause genetic change but low enough to allow the M_1 generation to survive and produce seeds (M_2) for further selection.

Application Techniques and the M_1 Generation

The process of inducing mutations is a precise laboratory to field procedure. For chemical mutagens, the following protocol is generally standard:

- **Pre-soaking:** Seeds are soaked in distilled water (usually for 6 – 12 hours). This softens the seed coat and initiates metabolic activity, making the DNA more susceptible to the chemical agent.
- **Chemical Treatment:** The pre – soaked seeds are immersed in the mutagenic solution (EMS, SA, or MMS) at a specific concentration and temperature.
- **Washing and Drying:** After the treatment period, seeds are thoroughly washed to remove residual chemicals and then air-dried.
- **Sowing the M_1 Generation:** The treated seeds are sown in the field to raise the M_1 generation. This generation is primarily used to observe the direct effects of the mutagen and to harvest seeds for the M_2 generation, where recessive mutations finally become visible.

Screening and Selection in the M_2 Generation

While the M_1 generation shows the immediate physiological impact of the mutagens, the M_2 generation is where the real genetic "treasure hunt" begins. Because most induced mutations are recessive, they only manifest visually when the plant inherits the mutated gene from both parents, which typically occurs during the segregation that happens in the second generation.

Visual Macro – Mutation Screening

The first step in the M_2 generation is the identification of macro – mutations – changes that are easily visible to the naked eye. In coriander, breeders look for:

- **Morphological Variants:** Changes in leaf shape (e.g., feathery vs. broad), plant height (dwarfing), or branching patterns.
- **Chlorophyll Mutations:** Variations in leaf color (albino, xantha, or chlorina), which serve as indicators of the mutagen's effectiveness, even if these specific plants aren't commercially viable.
- **Phenological Changes:** Plants that flower significantly earlier or later than the control group.

Quantitative Micro-Mutation Analysis

Not all improvements are visible. Micro – mutations involve small, cumulative changes in polygenic traits. These require statistical analysis and precise measurement:

- **Yield Components:** Measuring the number of umbels per plant, the number of seeds per umbellate, and the 1000 seed weight.

- **Essential Oil Content:** Using techniques like Hydro – distillation or Gas Chromatography (GC) to determine if the mutation has enhanced the concentration of Linalool, the primary aromatic compound in coriander.

Biotic and Abiotic Stress Screening

Mutant populations are often subjected to "stress tests" to identify resilient lines:

- **Disease Resistance:** Screening for resistance to common coriander pathogens like powdery mildew (Erysiphe polygoni) or stem gall.
- **Drought and Salinity:** Testing the M_2 and M_3 lines in controlled environments to find variants that can thrive in marginal soils or with less water.

Verification in the M_3 and M_4 Generations

Once a promising M_2 plant is identified, its seeds are harvested and sown in "plant to grow" progenies in the M_3 generation. This step is crucial to confirm that the observed trait is truly heritable and not just a temporary environmental fluke. If the trait remains stable and uniform through the M_4 generation, it is officially considered a "mutant line" and may be fast – tracked for variety release.

Comparison and Conclusion

To wrap up this chapter on coriander mutation breeding, it is essential to compare the primary tools at a breeder's disposal and summarize the strategic importance of these techniques.

1. Comparative Analysis: EMS vs. Gamma Radiation

Choosing between a physical and chemical mutagen depends on the breeder's specific goals. Below is a comparison of the two most common agents used in coriander research.

Feature	Gamma Radiation (Physical)	Ethyl Methane Sulphonate (EMS)
Primary Action	Physical energy (Ionizing radiation)	Chemical alkylation
Genetic Change	Large chromosomal aberrations/deletions	Precise point mutations (SNPs)
Ease of Use	Requires specialized facility (Gamma cell)	Can be done in a standard lab
Penetration	Uniform and high	Dependent on seed soaking/permeability
Coriander Impact	Effective for yield and structural traits	Excellent for oil quality and leaf traits
Handling Risk	High (Radiation safety protocols)	High (Carcinogenic; requires fume hood)

2. Summary and Future Outlook

The application of mutagenic agents like Gamma rays, EMS, and Sodium Azide has revolutionized our ability to “engineer” coriander. By carefully controlling the dosage and following rigorous pre – soaking and screening protocols, researchers can bypass the limitations of natural selection.

As we move forward, the integration of traditional mutation breeding with modern molecular markers will allow for even faster identification of desirable mutants. Instead of waiting for the M_2 generation to grow to maturity, breeders may soon be able to scan the DNA of young seedlings for specific genetic markers associated with high Linalool content or disease resistance.

3. Practical Takeaways for the Breeder

- **Start with the LD_ {50}:** Always determine the lethal dose for your specific coriander variety before starting a large-scale project.
- **Prioritize the M_2:** Devote the most resources to the second generation, as this is where recessive traits emerge.
- **Quality over Quantity:** A few stable, high-quality mutants in the M_3 generation are more valuable than hundreds of unstable variants in the M_1.

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Characterization of Bio-Nanoparticles Using Atomic Force Microscopy

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Abstract

Bio-nanoparticles play critical roles in nanomedicine, diagnostics, and molecular biology. Accurate characterization of their structural and mechanical properties is essential for understanding biological functions. Atomic Force Microscopy is a potent and adoptable method for nanoscale characterization. It is used for imaging and probing biological particles under near-physiological conditions. AFM operates in air or liquid without requiring extensive sample coating, thereby preserving native morphology. This paper comprehensively reviews the principles, operational modes, sample preparation strategies, and analytical approaches used in AFM-based characterization of bio-nanoparticles. Emphasis is placed on morphological analysis, including size distribution and surface topography, as well as nanomechanical measurements such as elasticity, stiffness, and adhesion using force spectroscopy and quantitative nanomechanical mapping. AFM is an essential tool for single-particle analysis, offering integrated structural and mechanical insights that complement conventional nanoscale characterization techniques.

Keywords: Atomic force microscopy, bio-nanoparticles, nanomechanical characterization, force spectroscopy, exosomes, viruses, nanomedicine, surface topography, single-particle analysis.

Introduction

Bio-nanoparticles encompass a wide variety of nanoscale biological and biologically engineered structures, including viruses, extracellular vesicles (such as exosomes), protein aggregates, nucleic acid nanostructures, and polymeric drug carriers. Due to their small size and pivotal roles in therapeutics, diagnostics, and fundamental biological processes, precise characterization of their structure, surface features, and mechanical properties is essential.

Atomic Force Microscopy is a potent and adoptable method for nanoscale characterization. AFM can function under ambient settings and aqueous environments enabling imaging and mechanical probing of biological particles in near-physiological states (Matias et al., 2025). AFM combines high spatial resolution with the ability to obtain force measurements, making it uniquely suited to study both morphology and nanomechanics of bio-nanoparticles.

Principles of Atomic Force Microscopy

AFM is a way of scanning probe microscopy in which a sample's surface is scanned by a sharp tip fixed on a flexible cantilever. The cantilever is deflected by interaction forces between the tip and the sample. A laser beam reflected onto a photodetector is used to track these deflections, allowing reconstruction of surface topography with nanometer-scale resolution (Matias et al., 2025).

Key Components Include

- **Cantilever and Tip:** The tip radius often determines lateral resolution; for biological samples, tips with radii <10 nm are common.
- **Piezoelectric Scanner:** Controls precise motion in x, y, and z.
- **Feedback Loop:** Maintains controlled force or oscillation during scanning.
- AFM uniquely measures both topography and force interactions, enabling dual characterization of structure and mechanical properties (Lam & Park, 2025).

AFM Operational Modes for Bio-Nanoparticles

- **Contact Mode**

Here, the sample surface is continuously in contact with the tip. While this yields high-resolution topographic maps, soft biological samples can deform or distort under lateral forces, making contact mode less desirable for fragile bio-nanoparticles.

- **Tapping (Intermittent Contact) Mode**

The cantilever periodically makes touch with the sample while oscillating close to its resonance frequency. Tapping mode minimizes shear forces and is widely used to image soft biological nanostructures such as exosomes, protein assemblies, and lipid vesicles (Lam & Park, 2025).

- **Non-Contact Mode**

The tip oscillates above the sample surface without touching it. This mode reduces tip-sample interaction but is less commonly used in liquid environments due to damping effects.

- **Force Spectroscopy and Nanomechanical Mapping**

In force spectroscopy, the tip moves back and forth from the sample surface to give force–distance curves, from which mechanical properties like elasticity, adhesion, and stiffness are derived. Advanced mapping creates spatial distributions of nanomechanical parameters across a particle or surface (Garcia & Tejedor, 2025).

Sample Preparation Strategies

- **Substrates**

Freshly cleaved mica is widely preferred due to its atomically flat surface, but functionalized glass or silicon wafers are also used when bio-affinity interactions are needed. Surface treatments (e.g., poly-L-lysine) can enhance adhesion of nanoparticles and vesicles.

- **Immobilization**

Bio-nanoparticles are often deposited by drop casting or incubation onto substrates. In liquid imaging, samples should remain hydrated in buffered solutions to mimic native biological environments.

- **Environmental Considerations**

AFM can operate in air or liquid. Liquid imaging preserves hydrated biological structures, avoids dehydration-induced artifacts, and enables dynamic studies, but requires more complex instrumentation.

Morphological Characterization

- **Size and Shape Analysis**

AFM images yield nanoscale height, width, and shape data. For spherical particles (e.g., virus capsids, exosomes), height measurements often provide more accurate size estimates than lateral dimensions due to tip convolution effects.

- **Surface Features**

Surface roughness, patterns, and protrusions (e.g., viral spikes) are resolved with high fidelity. Combining AFM with complementary techniques (e.g., TEM) can further validate observed morphology (Matias et al., 2025).

Mechanical Characterization

- **Elasticity and Stiffness**

Force–distance curves can be analyzed using contact mechanics methods (like Hertzian models) to estimate Young’s modulus, reflecting stiffness of particles like lipid vesicles and polymer nanoparticles. Such measurements help understand how bio-nanoparticles respond to mechanical stress (Lam & Park, 2025).

- **Adhesion and Binding Forces**

AFM can quantify adhesive forces between the tip (potentially functionalized with ligands or antibodies) and particles. This enables studies of receptor–ligand interactions at the single-particle level.

- **Nanomechanical Mapping**

Recent advances allow generation of spatially resolved maps of mechanical properties across the surface of a nanoparticle, revealing heterogeneities and molecular organization (Garcia & Tejedor, 2025).

Applications in Bio-Nanoparticle Research

- **Viral Nanoparticles**

AFM has been used to visualize morphology, stability, and assembly dynamics of viruses at nanoscale resolution in liquid. It also enables mechanical probing to assess capsid stiffness and genome release mechanics (de Pablo, 2024; Cantero et al., 2024). Recent reviews highlight AFM's role in studying foodborne viruses and other pathogens, including structural and mechanistic insights important for diagnostics and vaccine design (dos Santos Natividade et al., 2025).

- **Extracellular Vesicles and Exosomes**

Exosomes and microvesicles are key mediators of cell communication and are studied as disease biomarkers. AFM resolves their size and surface characteristics and can distinguish subpopulations based on mechanical signatures (Lam & Park, 2025; Creative Biostructure, 2026).

- **Nucleic Acid and RNA Nanostructures**

AFM is an essential way for imaging nanostructures of nucleic acids and monitoring dynamic conformational changes. It provides real-space visualization of RNA-based assemblies crucial for nanomedicine and RNA therapeutics (Lushnikov et al., 2023).

- **Polymeric and Lipid Nanoparticles**

Characterization of lipid carriers and polymeric drug delivery particles benefits from AFM's ability to assess both physical structure and mechanical stability, guiding design of optimized delivery systems.

- **Bio-Mechanobiology Studies**

AFM helps probe mechanobiological responses of cells and particles. Recent advances highlight its use in oncology and neurodegeneration to correlate mechanical signatures with pathophysiological states (Marcuello et al., 2025).

Advantages of AFM in Bio-Nanoparticle Characterization

- It provides nanometer-scale resolution under physiological conditions.
- It includes direct mechanical measurements (elasticity, adhesion).
- It provides 3D surface profiling without conductive coatings.
- It shows compatibility with liquid imaging for native structure preservation.
- It enables single-particle analysis, useful for study of heterogeneity within samples.

Limitations and Challenges

- Tip convolution artifacts can distort lateral dimensions.
- It has limited throughput compared to optical techniques.
- Sample preparation influences results heavily.
- Operator expertise is required for accurate force measurements.

Recent and Future Advances

- **High velocity AFM**

High velocity AFM enables real-time visualization of dynamic processes at the single-particle level, such as nanoparticle growth and biomolecular motion (Yang et al., 2023; Wakabayashi et al., 2026).

- **Nanomechanical Mapping Enhancements**

Advanced mechanical mapping strategies now generate spatial distributions of mechanical properties across complex surfaces, unlocking insights into molecular organization (Garcia & Tejedor, 2025).

- **Correlated Techniques & Functionalization**

Functionalized tips and correlative imaging with optical or fluorescence modalities extend AFM's capabilities into molecular recognition and multiplexed analyses.

Conclusion

AFM is a versatile and indispensable tool for the characterization of bio-nanoparticles. It provides detailed information on morphology, size, surface features, and nanomechanics of biological particles under near-physiological conditions. With ongoing technological advances and integration with complementary methods, AFM continues to expand frontiers in nanomedicine, virology, molecular biology, and nanoparticle engineering.

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Biotechnological and Bioengineering Approaches for Enhanced Artemisinin Production in the *Artemisia* genus

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Abstract

The genus *Artemisia* includes many medicinal and aromatic plants that produce various bioactive compounds. Artemisinin, a key compound used in artemisinin-based combination therapies, is recommended by the World Health Organization for malaria treatment. However, natural artemisinin levels in Artemisia species, especially *Artemisia annua*, are low and affected by environmental and genetic factors, posing challenges for large-scale production. This chapter reviews biotechnological strategies to enhance artemisinin production in Artemisia species and key regulatory enzymes involved in the biosynthetic pathway of artemisinin biosynthesis. The chapter highlights the importance of plant tissue culture techniques, micropropagation, and in vitro regeneration for rapidly multiplying elite chemotypes with higher secondary metabolite content. It also discusses the hairy root cultures as a reliable system for stable secondary metabolite production.

Keywords: *Artemisia*, Artemisinin, Plant biotechnology, Micropropagation, Hairy root culture, Elicitors, Metabolic engineering, Secondary metabolite enhancement.

Introduction

The genus *Artemisia*, within the Asteraceae family, comprises more than 500 species commonly found throughout Asia, Europe, and North America (Samy Selim et al., 2025). Several species, such as *Artemisia annua* and *Artemisia pallens*, are valued for their medicinal and aromatic properties. Among the diverse phytochemicals produced by this genus, the sesquiterpene lactone artemisinin is one of the most important natural products because of its potent antimalarial activity and growing therapeutic potential for anticancer, antiviral, and anti-inflammatory applications (Meng et al., 2021). Artemisinin is a fundamental component of current antimalarial treatments, as recommended by the World Health Organization through artemisinin-based combination therapy (ACTs) (Wang et al., 2020). However, the natural occurrence of artemisinin in plants is notably low, typically constituting only 0.01% to 1.0% of the plant's dry weight. This scarcity necessitates the exploration of alternative approaches to increase production (Zeinali et al., 2025).

To address this limitation, a range of biotechnological and bioengineering strategies have been devised, including plant tissue culture, hairy root technology, elicitor treatments, metabolic engineering, and genome-editing techniques such as CRISPR-Cas 19. These strategies are designed to boost artemisinin biosynthesis by altering the metabolic pathways, gene expression patterns, and cellular environments that play crucial roles in the production of secondary metabolites (Ramawat Kishan and Mérillon Jean-Michel, 2013).

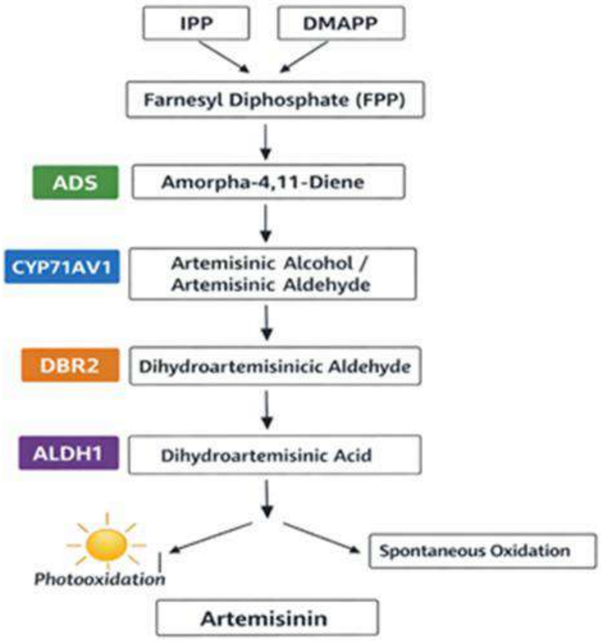

Fig: Artemisinin biosynthesis pathway

Artemisinin is primarily synthesized in the glandular trichomes of Artemisia species. This biosynthetic process begins with the isoprenoid pathway, which generates farnesyl diphosphate (FPP) as a universal precursor of sterols. (Mandal et al., 2014). In the initial committed step, the enzyme amorpha-4,11-diene synthase (ADS) facilitates the transformation of FPP into amorpha-4,11-diene (Zeinali et al., 2025). This is followed by a series of oxidation reactions, orchestrated by the cytochrome P450 enzyme CYP71AV1, which converts the intermediate into artemisinic alcohol and artemisinic aldehyde (Bertea et al., 2005). Subsequent enzymatic reactions involve artemisinic aldehyde Δ11(13) reductase (DBR2) and aldehyde dehydrogenase (ALDH1), culminating in the synthesis of dihydroartemisinic acid (Zhang et al., 2021). This compound then undergoes photooxidation and non-enzymatic transformations, ultimately resulting in the formation of artemisinin (Bachheti R.K et al., 2026).

Transcription factors and environmental conditions play pivotal roles in the precise regulation of these biosynthetic pathways (Mishra et al., 2025). Scientists have thoroughly explored the genetic alteration of key genes, such as ADS, CYP71AV1, DBR2, and ALDH1, to boost artemisinin production in both Artemisia plants and cultured tissues (Zhao et al., 2024).

The genetically modified roots of *Artemisia annua* upregulate crucial biosynthetic genes responsible for artemisinin production (Raypa Pratima et al., 2025). Hairy root systems serve as a powerful platform for employing metabolic engineering and gene-editing techniques to enhance the artemisinin biosynthetic pathway (Liu, C. et al., 2025).

Transcription factors and environmental conditions play pivotal roles in the precise regulation of these biosynthetic pathways (Kajla et al., 2023). Elicitors activate plant defense systems, thereby increasing the production of secondary metabolites (Jha, 2017). Research has shown that methyl jasmonate (Zhao Q et al., 2024), as well as chitosan and yeast extracts, promoted the production of secondary metabolites, thereby enhancing artemisinin yield in *Artemisia* cultures (Putalun et al., 2007).

Methyl jasmonate is recognized as a potent elicitor, primarily due to its ability to activate transcription factors that govern the genes responsible for artemisinin synthesis (Raypa Pratima et al., 2025). The application of methyl jasmonate significantly elevates artemisinin concentrations in both in vitro cultures and whole plants (Shen et al., 2016).

Integrating these methodologies with cutting-edge omics technologies and synthetic biology platforms allows us to advance our comprehension of artemisinin biosynthesis and facilitate the establishment of systems that yield high production levels of artemisinin.

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Biotechnology Applications in Wild Edible Plants

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Abstract

Wild edible plants (WEPs) represent an underutilized source of valuable genetic diversity with significant potential for crop improvement and sustainable agriculture. Their long-term adaptation to diverse environments has endowed them with traits such as stress tolerance and superior nutritional quality. However, many WEP species remain poorly documented and insufficiently conserved, making them vulnerable to habitat loss and genetic erosion. Challenges such as irregular germination, low yield stability, limited agronomic knowledge, and weak market systems hinder their wider cultivation.

Keywords: Biotechnology, Wild edible, Application

Introduction

Agricultural biotechnology integrates molecular biology, genetics, plant physiology, microbiology, and bioinformatics to enhance crop productivity, nutritional quality, and environmental adaptability. Unlike conventional breeding, biotechnology allows precise gene identification and manipulation for traits such as yield, nutrient enrichment, and stress tolerance. With challenges like climate variability, land degradation, and rising food demand, biotechnology supports development of resilient agricultural systems (Kumar and Dubey; Bhatia et al.; "The State of Food and Agriculture 2021").

Wild edible plants (WEPs) grow naturally in forests, grasslands, and wetlands and are traditionally consumed as food or medicine. They include fruits, leaves, roots, tubers, seeds, and flowers that contribute to local diets and cultural practices. WEPs are nutritionally rich, often containing higher micronutrients, dietary fiber, and bioactive compounds than cultivated crops, yet remain underutilized in formal agriculture (Łuczaj; Bharucha and Pretty; Hunter et al.).

Biotechnology is essential for WEPs due to irregular germination, low productivity, and lack of cultivation practices. Techniques such as molecular characterization, in vitro propagation, marker-assisted selection, and genome editing can improve propagation, stabilize traits, and accelerate domestication (Rao et al.; Chivenge). Integrating WEPs into food systems enhances dietary diversity and addresses "hidden hunger." Biofortification, reduction of anti-nutritional factors, and conservation tools like cryopreservation and DNA banking further support sustainable agriculture and genetic resource preservation (Tatiana; Engels and Ebert).

Diversity and Genetic Resources of WEPs

Wild edible plants represent a significant component of global biodiversity and serve as a valuable genetic resource for future crop improvement. These plants grow across diverse ecosystems, including forests, wetlands, and marginal lands, where they have developed adaptive traits that allow them to survive under varying environmental conditions. Although thousands of plant species are traditionally used as food worldwide, only a small proportion has been domesticated or incorporated into organized agricultural systems (Łuczaj; "The State of the World's Biodiversity for Food and Agriculture").

In tropical and subtropical regions, WEPs exhibit remarkable diversity in terms of morphology, physiology, and biochemical composition. This diversity supports ecosystem stability and provides essential nutritional and economic benefits to rural and indigenous populations (Bharucha and Pretty).

Genetic Variability in WEPs

Genetic diversity is fundamental to plant adaptation, evolution, and long-term survival. Wild edible plants generally possess greater genetic variability than cultivated crops because they have not undergone intensive selection and breeding processes (Hajjar and Hodgkin). This genetic richness enhances their ability to tolerate environmental stresses such as drought, salinity, and temperature extremes, as well as resistance to pests and diseases.

Molecular marker techniques, including RAPD, ISSR, SSR, and AFLP, have been widely used to assess genetic diversity in plant populations. Studies have demonstrated high levels of genetic variation within and between populations of wild species, indicating the presence of valuable alleles that can be utilized for crop improvement (Govindaraj et al.). Traits such as enhanced micronutrient content, antioxidant capacity, and stress tolerance are often more pronounced in wild species than in domesticated varieties (Chivenge).

Germplasm Resources and Conservation Status

The genetic material of WEPs, known as germplasm, is an important resource for agricultural sustainability and crop improvement. Germplasm includes seeds, tissues, and living plants that are conserved for research and breeding purposes. While major crops are well represented in global genebanks, wild edible plants are often underrepresented, increasing the risk of genetic loss (Engels and Ebert).

Conservation of WEP germplasm can be achieved through both in situ and ex situ approaches. In situ conservation involves protecting species in their natural habitats, allowing them to evolve under natural conditions and maintaining ecological interactions. Ex situ conservation includes seed banks, field collections, tissue culture repositories, and cryopreservation techniques that store genetic material outside its natural environment. Advances in biotechnology, particularly in vitro conservation and cryogenic storage, have improved the preservation of species that produce recalcitrant seeds or reproduce vegetatively (Pence, 2014).

Despite these efforts, many WEP species are threatened by deforestation, urbanization, climate change, and declining traditional knowledge. Reports from global conservation agencies indicate that several wild food plants are experiencing population decline, although many remain insufficiently studied (IUCN, 2022).

Challenges in Domestication and Cultivation

The transition of wild edible plants from natural ecosystems to cultivated systems presents several challenges. One major limitation is the lack of agronomic information regarding growth conditions, reproductive biology, and yield potential. Many WEPs exhibit seed dormancy, low germination rates, and poor seed viability, making large-scale cultivation difficult (Padulosi et al.).

Another challenge arises from the high genetic variability of WEPs. While genetic diversity is beneficial for adaptation, it can lead to inconsistency in plant characteristics, which is undesirable for commercial agriculture. Domestication requires selection for traits such as improved yield, larger edible parts, better taste, reduced bitterness, and synchronized growth patterns. However, excessive selection may reduce genetic diversity and increase vulnerability to environmental stress.

Biotechnology offers practical solutions to many of these challenges. Tissue culture techniques enable rapid multiplication of elite genotypes, while molecular markers facilitate early selection of desirable traits. Genomic tools can identify genes responsible for important characteristics, thereby accelerating breeding programs. However, the successful application of biotechnology requires integration with traditional knowledge and participatory approaches to ensure sustainability and community acceptance.

Conclusion

Wild edible plants and the genetic diversity they carry represent a resource of significant strategic importance for sustainable food production and improved human nutrition. Their innate genetic breadth confers adaptive advantages and breeding potential that few domesticated species can match. Yet, inadequate documentation and weak conservation infrastructure expose this wealth to significant risk. Preserving WEP germplasm, coupled with carefully managed domestication strategies, is essential if society is to fully utilize what these plants can offer. Meeting the biological, agronomic, and socioeconomic challenges through combined biotechnological and conservation-based approaches will allow WEPs to be used responsibly over the long term, while preserving the ecological balance and cultural inheritance tied to their continued existence.

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A Warming Planet and the Emergence of Green Innovation

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Introduction

Climate Transformation: Setting the Stage

Earth's climate is shifting at a pace unmatched in recorded history. Glaciers are retreating, sea levels are rising, tropical cyclones are intensifying, and drought is spreading across regions once characterised by seasonal rainfall. Concurrently, a surge of technological creativity is reshaping the global economy, driven not solely by ecological awareness but by economic imperatives and the growing recognition that prevailing models of energy use and resource consumption are fundamentally unsustainable. This article examines the physical science underlying contemporary climate change, its documented socio-ecological consequences, and the rapidly maturing technologies designed to mitigate its trajectory.

Mechanisms of Climate Destabilisation

The greenhouse effect is an essential biophysical mechanism — without it, mean surface temperatures would fall to approximately −18 °C. The present crisis stems not from this natural process but from its anthropogenic acceleration. Since industrialisation, atmospheric CO_2 has risen from roughly 280 ppm to over 420 ppm — a level unsurpassed in geological records spanning millions of years — driven by fossil fuel combustion, large-scale land clearance, and energy-intensive manufacturing.

The principal greenhouse gases — carbon dioxide, methane, and nitrous oxide — intercept outgoing infrared radiation and initiate amplifying feedback loops: retreating ice sheets expose darker surfaces with greater heat absorption; warming permafrost releases sequestered methane; and wildfires liberate stored organic carbon. Each process magnifies initial warming beyond the direct effect of emissions alone. The IPCC has documented that mean global temperatures already exceed pre-industrial baselines by approximately 1.1 °C. Remaining within the Paris Agreement's 1.5 °C threshold demands immediate, structurally comprehensive emissions reductions across every major economic sector.

Observed Impacts: A Crisis Already in Motion

Climate change has moved from prospective threat to documented reality. Arctic temperatures are rising several times faster than the global mean, accelerating sea ice loss and disrupting Indigenous subsistence practices. Across South Asia, sub-Saharan Africa, and semi-arid Latin America, erratic precipitation and prolonged drought are undermining agricultural yields and food security. Low-lying island states face existential inundation risk, with several communities already undergoing planned relocation — constituting some of the earliest populations formally displaced by climate-induced change. Wealthier nations are equally exposed: wildfire extent and severity have risen markedly across California, southeastern Australia, and the Mediterranean, while coastal flooding is penetrating previously secure zones, imposing mounting fiscal and public health burdens globally.

The Renewable Energy Transition

Among the most consequential developments in climate mitigation is the dramatic cost compression in renewable energy. Over the past decade, utility-scale solar photovoltaic generation costs fell by over 90%, with onshore and offshore wind following comparable trajectories. In a growing number of markets, renewables now represent the lowest-cost option for new electricity capacity, even without pricing carbon externalities. A substantial and expanding proportion of newly commissioned generation capacity globally originates from non-carbon sources.

Nonetheless, the variability of solar and wind generation poses challenges for grid stability, requiring complementary investment in storage and intelligent grid management. Lithium-ion battery costs have declined sharply, while pumped hydro, compressed air, green hydrogen, and next-generation electrochemical technologies are advancing through demonstration stages — collectively establishing the technical feasibility of high-penetration renewable electricity systems.

Electrification of Transport

Transport accounts for approximately one quarter of global CO_2 emissions. Electric vehicles have rapidly transitioned from a marginal segment to a mainstream automotive category: global battery-electric and plug-in hybrid sales surpassed 10 million units in 2022. Energy costs per kilometre for electric propulsion are now significantly lower than for internal combustion equivalents. Electrification is extending beyond passenger cars — electric bus fleets are penetrating urban transit systems in China and Europe, and electric two- and three-wheelers are transforming mobility across the developing world. For harder-to-abate sectors such as aviation and maritime shipping, green ammonia, synthetic methanol, and liquid hydrogen are under active development as zero-carbon energy carriers.

Green Hydrogen and Heavy Industry Decarbonisation

Certain industrial processes — primary steel production, cement calcination, bulk chemical synthesis, and long-haul freight — require high-grade thermal energy or energy-dense fuels that current batteries cannot practically supply. Green hydrogen, produced by electrolysing water using renewable electricity, offers a transformative solution: its end use generates only water vapour, eliminating combustion-related carbon entirely. As electrolyser manufacturing scales and renewable input costs fall, green hydrogen production costs are declining progressively. Nations with abundant renewable resources — Australia, Chile, and several EU member states — are establishing large-scale production infrastructure, positioning themselves as future exporters of carbon-neutral fuel and chemical precursors.

Carbon Dioxide Removal

Scientific consensus holds that active removal of accumulated atmospheric CO_2 will be necessary even under the most ambitious emissions reduction scenarios. Ecosystem-based approaches — conserving and restoring forests, coastal wetlands, peatlands, and agricultural soils — represent immediately scalable, cost-effective strategies, though ensuring the permanence and measurability of sequestration remains a governance challenge. On the engineered side, Direct Air Capture technology extracts CO_2 from ambient air using chemical sorbents; removal costs, currently in the range of several hundred US dollars per tonne, are projected to decline substantially as the technology scales. Complementary approaches under development include enhanced silicate rock weathering, ocean alkalinity enhancement, and bioenergy with geological carbon storage. An effective response will require an integrated portfolio spanning both natural and engineered pathways.

Equity, Justice, and the Political Economy of Transition

A critically underemphasised dimension of the climate challenge is the profound inequity embedded in its causes and consequences. Nations that have contributed negligibly to cumulative emissions — concentrated in low-income regions of sub-Saharan Africa, South and Southeast Asia, and the Pacific — bear the severest impacts: food system disruption, displacement, extreme heat exposure, and coastal inundation. This asymmetry constitutes a fundamental question of distributive justice with direct implications for international governance. Simultaneously, the shift away from fossil fuel-dependent economies imposes significant adjustment costs on specific communities and workers. A just transition framework requires that decarbonisation pathways generate quality employment, distribute clean energy benefits equitably, and ensure that historically high-emitting nations provide substantive financial and technical support to vulnerable countries. Current international climate finance commitments fall substantially short of estimated requirements — a shortfall that represents not merely a moral deficiency but a concrete impediment to the multilateral cooperation on which effective global climate governance depends.

Conclusion: The Urgency of the Present Decade

The physical evidence is unambiguous: the window within which the most damaging warming trajectories can be averted is finite and rapidly contracting. Yet the technological foundations for a decisive emissions reduction — photovoltaic and wind generation, grid-scale storage, electric mobility, green hydrogen, and carbon dioxide removal — are increasingly robust, economically competitive, and deployable at scale. The principal constraints lie not in engineering but in institutional will, capital mobilisation, and coordinated governance. The decisions enacted before 2030 will substantially determine the planet's thermal trajectory across the next several centuries. Green innovation offers a credible pathway toward a sustainable future — one premised not on austerity but on affordable clean energy, healthier urban environments, and ecologically resilient landscapes. That future is an achievable possibility, contingent on the quality of resolve that the scale of the climate emergency demands.

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Integrated Management of Fungal Diseases in Fruit Crops: Sustainable Approaches and Future Perspectives

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Abstract

Fruit crops contribute significantly to global nutrition, livelihood security, and agricultural sustainability. However, their productivity is frequently threatened by fungal pathogens that affect plants during vegetative growth, fruit development, and storage. Diseases such as anthracnose, wilt, leaf spot, dieback, and fruit rot lead to substantial quantitative and qualitative losses. Conventional control strategies have relied heavily on chemical fungicides, but concerns regarding resistance development, environmental contamination, and food safety have necessitated alternative approaches. A sustainable solution is provided by Integrated Disease Management (IDM), which involves the integration of cultural practices, biological control measures, botanical inputs, and need based chemical interventions. This chapter discusses major fungal diseases of fruit crops and highlights eco-friendly and integrated strategies for long-term disease management.

Keywords: Fruit crops, fungal pathogens, Integrated Disease Management, Biological control, Sustainable agriculture

Introduction

Fruit cultivation occupies a vital position in modern agriculture due to its contribution to dietary diversity, nutritional enrichment, and economic development. Fruits provide essential micronutrients, vitamins, natural antioxidants, and dietary fiber that are fundamental to human health. In many regions, fruit farming serves as a dependable source of income, especially for small-scale growers.

Although fruit crops are economically and nutritionally important, they are prone to infection by a diverse range of fungal pathogens affecting multiple organs, including leaves, stems, roots, flowers, and fruits, throughout their growth stages. The consequences are often severe, resulting in reduced yields, inferior fruit quality, shortened shelf life, and increased production costs. Effective management of fungal diseases, therefore, is not merely a plant protection issue but a crucial component of sustainable horticulture.

Important Fungal Diseases Affecting Fruit Crops

Fungal diseases in fruit crops exhibit diversity in symptoms, modes of infection, and environmental preferences. Several diseases occur repeatedly across different fruit species and agro-climatic regions.

- **Anthracnose**

Anthracnose is considered one of the most destructive fungal diseases affecting fruit crops Such as mango, guava, papaya, and citrus. It is commonly associated with species of Colletotrichum. It is characterized by the formation of minute, dark lesions on leaves and fruits, which gradually expand and become depressed. Under favorable humidity, spore masses may appear on infected tissues. Anthracnose is distinguished by its ability to cause latent infections that become active during the ripening stage, leading to substantial postharvest damage.

- **Wilt Diseases**

Wilt diseases are predominantly caused by soil-borne fungal pathogens such as Fusarium and Macrophomina species. These pathogens invade the vascular tissues, disrupting water and nutrient transport. Initial symptoms include yellowing and drooping of leaves, followed by progressive wilting and plant death. Since these pathogens persist in soil for extended periods, management becomes challenging and infected orchards may suffer long-term productivity decline.

- **Leaf Spot and Blight**

In many fruit crops, leaf spot diseases are prevalent and are caused by fungi such as Alternaria, Cercospora, and Pestalotiopsis. These diseases are characterized by necrotic lesions, often surrounded by chlorotic margins. Severe infections reduce photosynthetic efficiency and may cause premature defoliation, ultimately affecting fruit development.

Fruit Rot and Storage Diseases

Post-harvest fungal pathogens such as Lasiodiplodia, Rhizopus, Aspergillus, and Penicillium contribute significantly to storage losses. Infection may occur in the field or through mechanical injuries during harvesting and transportation. High temperature and humidity accelerate fungal growth, leading to rapid deterioration of fruits during storage and marketing

Constraints of Chemical-Based Management

Synthetic fungicides are widely used for quick control of fungal diseases in orchards, including copper compounds, carbendazim, triazoles, and strobilurins. While effective, excessive reliance leads to problems such as development of resistant pathogens. Chemical residues on fruits raise concerns for human health and export quality. Additionally, these chemicals can cause environmental pollution and harm beneficial soil microorganisms. These challenges highlight the need to reduce dependence on chemical fungicides and adopt more sustainable disease management approaches.

Biological Control as a Sustainable Alternative

Biological control has emerged as an eco-friendly approach to disease management, wherein beneficial microorganisms inhibit pathogens through mechanisms such as competition, antibiosis, parasitism, and the activation of plant defense responses.

- **Fungal Antagonists**

Species of Trichoderma are among the most extensively studied fungal bio-agents. They colonize the rhizosphere effectively and inhibit pathogens by producing enzymes and antifungal metabolites. These beneficial effects on plant growth and resistance highlight their value as integral components of integrated disease management systems.

- **Bacterial Antagonists**

Bacterial species such as Pseudomonas fluorescens and Bacillus spp. act as effective biocontrol agents against fungal pathogens by producing antibiotics and enzymes that degrade fungal cell walls. They also enhance plant defense through induced systemic resistance, reducing disease severity. Although environmentally safe, their effectiveness depends on climatic conditions and application methods, making proper formulation and field validation essential for consistent performance.

Potential of Botanicals

Plant-derived extracts are promising tools for sustainable plant protection. Extracts from neem, garlic, ginger, and other plants show antifungal activity by inhibiting pathogen growth and spore germination. Botanicals are biodegradable, less toxic, and leave minimal residues. However, their effectiveness can vary with preparation, concentration, and environmental conditions. Standardization and scientific validation are essential for reliable use.

Integrated Disease Management (IDM): Combining Strategies for Effective Control

Integrated Disease Management (IDM) combines preventive, biological, and limited chemical methods for effective disease control. It emphasizes eco-friendly practices like sanitation, pruning, crop rotation, and resistant varieties. Selective fungicides are used only when necessary, reducing chemical dependence and promoting sustainable, environmentally safe crop production.

Future Directions

The future of fungal disease management lies in integrating advanced technologies with sustainable practices. Molecular diagnostics enable early and accurate pathogen detection, while breeding resistant cultivars offers long-term solutions. Innovations in bio-formulations, nanotechnology, and precision agriculture can improve control efficiency. Farmer education is equally important to promote the adoption of integrated, responsible, and sustainable plant protection practices.

Conclusion

Fungal diseases significantly affect fruit crop productivity worldwide. While chemical fungicides are useful, their limitations highlight the need for eco-friendly alternatives. Biological control agents, botanicals, and improved cultural practices offer sustainable solutions. Integrated Disease Management provides a balanced approach, combining effectiveness with environmental safety, and is essential for ensuring long-term productivity, environmental protection, and food security.

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Advances in Bioherbicides: Integrating Molecular Science and Precision Agriculture

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Abstract

The chapter reviews through a critical view the bioherbicides as the innovation-based products that merge molecular biology, omics, nano-formulation, synthetic biology, and precision agriculture. It integrates views of the world and India to emphasize technology development, multi-targets, environmentally soundness and climate robustness to make bioherbicides the pillars of the age of technology, which are based on science and broaden the sustainable management of weeds in the next generation.

Introduction

Modern agriculture is at a critical crossroad with weed management, with increasing levels of herbicide resistance, environmental degradation and climate changes putting pressure on the sustainability of traditional chemical control methods. The quick development of resistant weed strains has become the issue of hundreds of weed species all over the globe, which is why the use of single-target synthetic herbicides is at a disadvantage, and biologically intelligent options must be introduced into the market. At the same time, the growing number of regulatory requirements and environmental issues require effective and environmentally friendly solutions. Here, bioherbicides can be seen not just as alternatives, but rather as being technologically superior, systems based so as to incorporate microbiology, molecular science and precision control and thus re determine sustainable weed management.

Reimagining Weed Management through Biological Innovation

Weeds are a major constraint in global agriculture, causing 20–40% crop losses and over USD 100 billion annually in yield and management costs. In India, weeds lead to 30–35% losses in rainfed farms and 15–20% in irrigated systems, amounting to more than 1.5 lakh crore each year. Although the Green Revolution improved weed control through synthetic herbicides, prolonged use has produced ecological and evolutionary consequences.

More than 500 cases of herbicide resistance have been reported worldwide across over 270 weed species and most herbicide classes. In India, repeated application of single-site herbicides has led to resistant weeds such as *Phalaris minor* and *Echinochloa colona*. Additional concerns include groundwater contamination, non-target toxicity, disruption of soil microbes, and risks to human health, prompting stricter regulations.

These challenges have accelerated interest in bioherbicides biological agents that control weeds using natural processes. By integrating microbiology, plant physiology, and molecular science, bioherbicides offer sustainable, targeted, and environmentally friendly alternatives compatible with climate-resilient and regenerative agriculture.

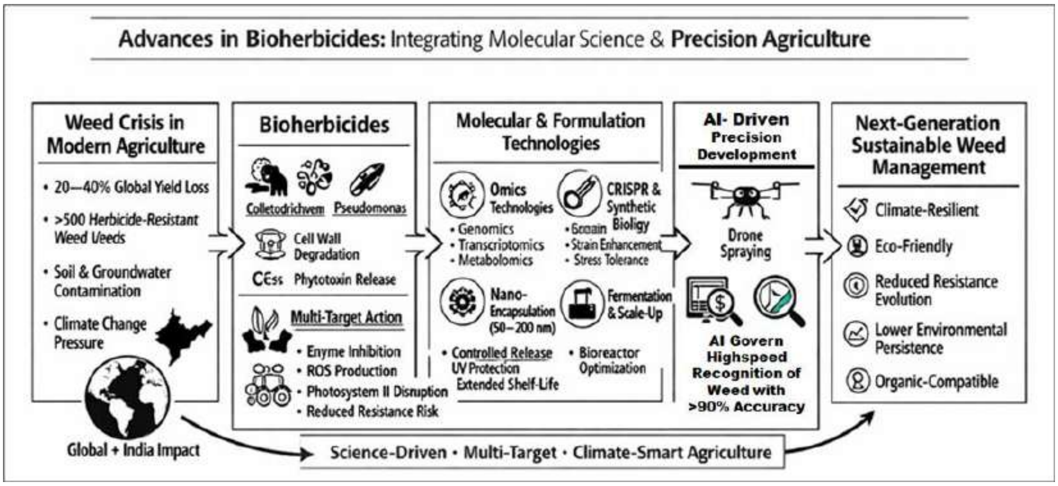

Figure 1: Illustrating the transition from herbicide resistance challenges to multi-target bioherbicides enhanced by advance molecular technologies and ML-AI-driven precision agriculture for climate-resilient weed management.

Technological Innovations Driving Bioherbicide Development

Advances in science and technology have significantly improved bioherbicide development. Omics approaches genomics, transcriptomics, proteomics, and metabolomics enable precise identification of virulence factors, toxin biosynthetic pathways, and host-specific regulatory mechanisms. Transcriptomic profiling under simulated field stresses reveals pathways enhancing environmental tolerance. Metabolomics, supported by high-resolution mass spectrometry and nuclear magnetic resonance, accelerates discovery of allelochemicals and bioactive metabolites with herbicidal potential.

Genetic engineering and synthetic biology further enhance efficiency. CRISPR-Cas systems allow targeted genome editing to increase toxin production, optimize metabolic pathways, and remove undesirable traits. Engineering stress-tolerant microbes and designing synthetic microbial consortia improve resilience and combined enzymatic degradation with phytotoxin secretion.

Formulation technologies address stability issues. Biodegradable polymers such as polylactic acid and chitosan protect active agents from UV degradation and desiccation, improve adhesion and penetration, and extend shelf life. Controlled-release matrices regulate diffusion, while optimized bioreactors enhance scalability and cost efficiency. Integration with precision agriculture, including drone spraying and AI-based weed recognition, enables targeted, sustainable bioherbicide application.

Applications and Comparative Advantages in Modern Agriculture

Bioherbicides are increasingly accepted in agricultural systems, particularly in wet-soil row crops such as soybean, maize, and rice, where they complement integrated weed management. Microbial agents targeting *Echinochloa* spp. in rice reduce synthetic herbicide use and delay resistance. Similarly, biological approaches are explored in Indian wheat systems to manage herbicide-resistant *Phalaris minor*.

Organic farming provides major opportunities, covering over 2.8 million hectares in India and 75 million hectares globally. Bioherbicides are biodegradable, residue-free, and support beneficial soil microbes like nitrogen-fixing bacteria and mycorrhizae. They also control aquatic weeds; for example, bioregulators manage *Eichhornia crassipes* without harming aquatic ecosystems.

Compared to synthetic herbicides, bioherbicides show lower non-target toxicity and shorter environmental persistence. Although slower initially, their multi-target action and integration with cultural and mechanical practices enhance long-term sustainability and resistance management.

Challenges, Future Prospects, and the Road Ahead

Bioherbicides face scientific and operational challenges despite progress. Their effectiveness is sensitive to environmental factors such as temperature, humidity, and UV radiation, which affect microbial survival. Enhancing stress tolerance through heat-shock proteins and osmoprotectants can improve performance in tropical climates. Limited shelf life, especially without cold-chain storage, remains a constraint, though nano-encapsulation is improving stability and viability. Regulatory approvals ensure biosafety but are often slow and costly, highlighting the need for harmonized international frameworks.

Future bioherbicides will integrate adaptive features, including stimulus-responsive systems activated by root exudates. Microbiome engineering aims to create stable microbial consortia, while artificial intelligence supports discovery of new compounds. Climate change, with rising temperatures, will alter weed distribution, requiring climate-resilient bioherbicides combined with precision agriculture tools for efficient and environmentally sustainable application.

Conclusion

New technological development in genomics, CRISPR-based strain enhancement, nano-formulation and AI-directed precision application has enhanced their reliability and scaling in the field. Nevertheless, the issues associated with the variability of the environment, stable shelf-life, mass-production, and regulatory harmonization are still acute.

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Innovations in Fertilizer Technology

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Abstract

Global food security is largely dependent on agriculture, and the Green Revolution was a turning point in raising crop output to keep up with population growth. Despite being successful in increasing yields, conventional agricultural practices and chemical fertilizers have had detrimental effects on the environment, including soil deterioration, water pollution, and biodiversity loss. Innovations in fertilizer technology, particularly biofertilizers, offer a sustainable solution by enhancing nutrient availability, improving soil health and promoting eco-friendly farming practices. Biofertilizers comprise living microorganisms that fix atmospheric nitrogen, dissolve phosphorus, and promote plant development via organic biological processes. They play a critical role in sustainable agriculture by decreasing chemical dependency, improving crop yield and maintaining ecological balance. This chapter discusses the types, mechanisms, applications and benefits of biofertilizers, focusing on nitrogen-fixing and phosphate-solubilizing microorganisms and highlights their importance in ensuring sustainable agricultural growth.

Introduction

India, under the leadership of Dr. M. S. Swaminathan, adopted the Green Revolution to address the rising food demands caused by rapid population growth and frequent crop failures. Traditional farming methods, combined with low-yielding local crop varieties, were insufficient to ensure food security, leading to dependence on imports. By adopting high-yielding varieties (HYVs), chemical fertilizers, pesticides and improved irrigation practices, India aimed to achieve self-sufficiency in food production.

While modern fertilizers have significantly increased crop productivity, excessive or improper use has adversely affected soil fertility, water quality, air purity and biodiversity. These challenges have necessitated a shift toward sustainable, eco-friendly solutions such as biofertilizers.

Biofertilizers are preparations containing beneficial living microorganisms. Beneficial live microorganisms included in biofertilizers enhance nutrient availability and encourage plant growth through organic biological processes. By fixing atmospheric nitrogen, solubilizing vital elements like phosphorus, and promoting root growth, they improve soil fertility. Biofertilizers promote long-term soil health and are more environmentally friendly than chemical fertilizers.

Sustainable agriculture emphasizes increasing crop productivity while conserving natural resources and maintaining environmental balance. By increasing soil microbial diversity and decreasing reliance on chemical inputs, biofertilizers contribute significantly to sustainable agricultural practices, enhancing nutrient cycling, soil structure and resilience against environmental stresses.

Definition

"Biofertilizer is a living fertilizer material composed of microbial inoculants which can increase the fertility of the soil."

Need for Biofertilizers

Biofertilizers are a natural boon to agriculture. Containing specific microbial strains preserved in eco-friendly carriers, they multiply rapidly in the soil and provide essential nutrients to plants. Unlike chemical fertilizers, biofertilizers are non-toxic and maintain soil fertility naturally. The organic matter produced contains growth regulators, enzymes and decomposed materials, ensuring nutrient availability within tolerable limits while avoiding environmental harm.

Types and Scope of Biofertilizers

The microorganisms used and their functional roles determine the classification of biofertilizers:

- **Nitrogen-Fixing Biofertilizers:** e.g., *Rhizobium, Azotobacter, Azospirillum, Cyanobacteria, Azolla.*
- **Phosphate-Solubilizing Biofertilizers (PSB):** e.g., *Pseudomonas, Bacillus, Mycorrhizae.*

Nitrogen-Fixing Biofertilizers

Introduction

As a vital component of proteins, nucleic acids, and chlorophyll, nitrogen is a nutrient that plants need to grow. Despite making up over 78% of the air, atmospheric nitrogen (N_2) is not available to plants in its inert state. Using nitrogen-fixing microorganisms and the enzyme complex nitrogenase, biological nitrogen fixation (BNF) transforms atmospheric nitrogen into ammonia. High crop yields require an adequate supply of nitrogen, and BNF offers a sustainable substitute for commercial nitrogen fertilizers.

Nitrogen-fixing microorganisms may be classified as either symbiotic or non-symbiotic:

- **Symbiotic:** *Rhizobium* species forming nodules in legumes.
- **Non-symbiotic:** Free-living or associative bacteria such as *Azotobacter, Azospirillum* and *Cyanobacteria.*

These microorganisms not only fix nitrogen but also produce growth-promoting substances that enhance plant development.

Rhizobium Biofertilizers

Rhizobium species form symbiotic associations with leguminous plants. Nodulation begins when plant roots release flavonoids, which attract Rhizobium and activate nod genes. The bacteria generate nod factors that trigger root hair curling and the production of infection threads, allowing Rhizobium to enter root cells and differentiate into nitrogen-fixing bacteroids. Effective nodulation occurs within four weeks after planting.

Uses

- Fix 50–200 kg N2/ha per crop season.
- Increase yield by 10–35%.
- Improve soil fertility through root secretions.
- Enhance germination and crop yield through seed treatment.

Azotobacter

- **Morphology:** *Azotobacter* cells are oval or spherical, mobile due to flagella and produce a protective mucus layer in later stages. They form cysts resistant to UV light, drying and environmental stress.

Physiological Properties

- Aerobic heterotrophs, utilizing carbohydrates, alcohols and organic acids.
- Optimal nitrogen fixation at pH 7.0–7.5.
- Produce pigments like melanin to protect nitrogenase.

Role in Soil Fertility

- Fixes ~20 kg N2/ha annually.
- Enhances uptake of N, P, Fe and Zn.
- Produces growth-promoting substances like IAA, gibberellins and cytokinins.
- Increases plant resistance to stress, dry matter accumulation, and leaf area index (LAI).
- Produces antibiotics that inhibit soil pathogens.

Azospirillum

Characteristics: Gram-negative, aerobic, nitrogen-fixing microbes that do not form nodules. Associative symbiosis with crops like maize, sugarcane, sorghum and pearl millet.

Mechanisms

- Generate growth hormones, such as cytokinins, gibberellins, and IAA.
- Improve nutrient uptake and root development.
- Promote stress tolerance (drought, salinity, acidic conditions).

Uses

- Fix 20–40 kg N2/ha.
- Increase yield by 15–30%.
- Improve water and mineral uptake.
- Enhance vegetative growth and root development.

Cyanobacteria

Also called blue-green algae, these photosynthetic bacteria fix nitrogen in anaerobic conditions using heterocysts. Found in soil, freshwater and symbiotic associations (e.g., *Anabaena* with *Azolla*).

Ecological Benefits:

- Fix atmospheric nitrogen for plant use.
- Enhance soil fertility in rice paddies and wetland ecosystems.

Azolla

In symbiosis with Anabaena azollae, a floating water fern is able to fix nitrogen more quickly than many legumes. Used as a green manure in rice fields, Azolla improves nitrogen availability, increases rice yield (14–40%) and suppresses weeds and pests.

Phosphate-Solubilizing Microorganisms

Despite abundant soil phosphorus, much of it remains insoluble and unavailable to plants. Phosphate-solubilizing bacteria (PSB) and fungi convert insoluble phosphorus to soluble forms through organic acids and phosphatases.

Examples

- Bacteria: *Pseudomonas, Bacillus*
- Fungi: *Aspergillus, Penicillium, Trichoderma*
- Mycorrhizae: *Glomus, Endogone, Gigaspora*

Mechanism

- Organic acids chelate cations bound to phosphate, releasing soluble phosphorus.
- Mycorrhizae increase root surface area and phosphorus uptake.
- AM fungi facilitate metal homeostasis and detoxification of toxic substances.

Uses

- Solubilize insoluble phosphorus.
- Improve soil fertility.
- Enhance nutrient uptake.
- Increase crop yield by 200–500 kg/ha.

Why Biofertilizers for Sustainable Growth?

1. **Improve Soil Fertility Naturally:** Enhance nutrient availability through nitrogen fixation and phosphorus solubilization.
2. **Reduce Chemical Fertilizer Dependence:** Minimize environmental pollution and production costs.
3. **Maintain Soil Health:** It boosts the amount of organic matter, microbial diversity, and soil structure.
4. **Eco-Friendly:** Non-toxic and non-polluting, prevent nutrient runoff.
5. Enhance Crop Yield and Quality: Promote plant growth, stress resistance and nutrient uptake.
6. **Support Long-Term Sustainability:** Ensure continuous agricultural productivity and ecological balance.

Conclusion

Innovations in fertilizer technology, particularly the use of biofertilizers, are central to achieving sustainable agricultural growth. Nitrogen-fixing and phosphate-solubilizing microorganisms, including *Rhizobium, Azotobacter, Azospirillum, Cyanobacteria, Azolla* and *Mycorrhizae,* are essential for increasing agricultural output, boosting soil fertility, and lowering dependency on chemical fertilizers. By harnessing the natural capabilities of these microorganisms, farmers can maintain soil health, reduce environmental risks and ensure food security for future generations. Biofertilizers represent a crucial step toward environmentally responsible, cost-effective and sustainable agriculture. Their widespread adoption will allow agriculture to meet the growing food demands while preserving the planet's ecological integrity

Future Perspectives

The need for sustainable farming methods is become more pressing as the world's population continues to grow. Innovations in fertilizer technology, particularly biofertilizers, offer immense potential to meet these challenges while preserving environmental integrity. In the future, research and development are expected to focus on the following areas:

- **Development of Multi-Functional Biofertilizers:** Future biofertilizers may combine multiple microbial strains with complementary functions, such as nitrogen fixation, phosphate solubilization, potassium mobilization and production of growth-promoting substances. Such multi-functional formulations can provide a balanced nutrient supply, enhance plant resilience and reduce the need for chemical inputs.

- **Genomic and Molecular Advances:** Advances in genomics, metagenomics and molecular biology will allow the identification and engineering of highly efficient microbial strains. Tailored microbial consortia can be developed to perform optimally under specific soil and climatic conditions, increasing their effectiveness and consistency in the field.
- **Precision Agriculture and Microbial Delivery Systems:** Integration of biofertilizers with precision agriculture technologies, including smart sensors, drones and automated nutrient monitoring systems, will enable targeted and efficient application. Controlled-release formulations and novel carriers will enhance microbial survival, colonization and activity, leading to higher nutrient use efficiency.
- **Climate-Resilient Agriculture:** Climate-smart agriculture will heavily rely on biofertilizers. Some strains can increase a plant's resistance to abiotic conditions like salt, drought, and extremely high or low temperatures. Maintaining crop productivity in the face of climate change will need the creation of stress-adapted microbial inoculants.
- **Integration with Circular Economy Practices:** Future strategies will focus on integrating biofertilizers with organic amendments, crop residues and wastewater recycling to promote circular nutrient flows. This approach can further reduce chemical fertilizer dependency and minimize environmental pollution while supporting soil health.
- **Policy, Awareness and Farmer Adoption:** For biofertilizers to achieve their full potential, increased awareness, farmer training and supportive government policies are essential. Subsidies, incentives for sustainable practices and quality certification systems will encourage widespread adoption, particularly among smallholder farmers.

In conclusion, the future of fertilizer technology lies in the development of eco-friendly, efficient and multifunctional biofertilizers, supported by scientific innovations and precision farming techniques. By combining modern technology with natural microbial processes, agriculture can achieve higher productivity, sustainability and resilience, ensure food security while conserve the planet’s ecological balance

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Biological Inputs for Future Agriculture: Impact of *Glomus* on Soybean Performance

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Abstract

The transition toward sustainable and climate resilient agriculture necessitates the integration of biological inputs that enhance nutrient efficiency, soil health, and crop productivity. Among beneficial soil microorganisms, arbuscular mycorrhizal fungi (AMF), particularly species of the genus *Glomus*, have emerged as pivotal bio-inoculants for leguminous crops. Soybean (*Glycine max* L. Merr.), a globally important oilseed and protein crop, exhibits strong mycorrhizal dependency, especially under nutrient-limited conditions. This chapter synthesizes current advances in the biology, ecology, and functional mechanisms of *Glomus* and critically evaluates its impact on soybean growth, nutrient uptake, nodulation, stress tolerance, and yield performance. Mechanistic insights into phosphorus solubilization, hyphal-mediated nutrient transport, hormonal modulation, and synergistic interactions with Rhizobium are discussed. Empirical evidence from field and controlled experiments demonstrates significant improvements in root colonization, biomass accumulation, chlorophyll content, pod number, and seed yield following *Glomus* inoculation. Furthermore, the role of *Glomus* in mitigating abiotic stresses such as drought and salinity is examined in the context of climate smart agriculture. The chapter concludes with future prospects for integrating *Glomus* based biofertilizers into sustainable soybean production systems and highlights research gaps in molecular interactions and large-scale application strategies.

Keywords: Arbuscular mycorrhizal fungi, *Glomus*, Soybean, Biological inputs, Sustainable agriculture, Nutrient uptake.

Introduction

Global agriculture faces serious challenges due to soil degradation, excessive fertilizer dependency, and climate variability. Sustainable intensification strategies increasingly emphasize biological inputs as eco-friendly alternatives to synthetic agrochemicals (Berruti et al., 2016).

Arbuscular mycorrhizal fungi (AMF), belonging to the phylum Glomeromycota, form mutualistic associations with nearly 80% of terrestrial plants (Brundrett, 2009). The genus *Glomus* is one of the most widely distributed and agriculturally significant AMF groups (Smith & Read, 2008). Its symbiotic relationship with soybean (*Glycine max* L. Merr.) is particularly relevant due to soybean's high phosphorus demand and its global importance as an oilseed and protein crop. The integration of *Glomus*-based inoculants into soybean cultivation systems represents a promising strategy for enhancing nutrient use efficiency and reducing chemical fertilizer inputs (Berruti et al., 2016).

Biology and Functional Attributes of *Glomus*

- **Taxonomy and Morphology**

Glomus species form arbuscules, vesicles, and extensive extraradical hyphal networks. Arbuscules are the primary sites for nutrient exchange between fungus and host plant (Smith & Smith, 2011). Vesicles function as storage organs, while hyphal networks extend beyond root depletion zones, enhancing nutrient absorption efficiency (Smith & Read, 2008).

- **Life Cycle**

The life cycle includes spore germination, hyphal growth, root penetration, arbuscule development, and sporulation (Brundrett, 2009). Host root exudates initiate signaling pathways that facilitate fungal colonization and symbiosis establishment.

Mechanisms of *Glomus*-Mediated Enhancement in Soybean

- **Improved Phosphorus Uptake**

Phosphorus (P) is relatively immobile in soil. *Glomus* hyphae access distant phosphate pools and transport them to the host plant via specialized phosphate transporters (Chen et al., 2018). Mycorrhizal associations significantly enhance P-use efficiency (Smith & Smith, 2011).

- **Enhanced Nitrogen Fixation and Nodulation**

Soybean establishes symbiosis with nitrogen-fixing bacteria such as *Bradyrhizobium japonicum*. Dual inoculation with AMF enhances nodulation and nitrogenase activity due to improved phosphorus availability and metabolic coordination (Smith & Read, 2008).

- **Hormonal and Physiological Modulation**

Mycorrhizal colonization influences phytohormone regulation, enhancing auxins, cytokinins, and gibberellins while modulating stress-related hormones. These physiological changes improve chlorophyll synthesis and photosynthetic efficiency (Smith & Smith, 2011).

- **Improved Water Relations and Stress Tolerance**

Under drought stress, AMF-colonized soybean plants exhibit improved osmotic adjustment, stomatal conductance, and relative water content (Begum et al., 2019). Earlier research also demonstrated the protective role of vesicular-arbuscular mycorrhizae under environmental stress conditions (Sylvia & Williams, 1992).

Impact on Growth and Yield Parameters

Experimental studies report significant improvements in plant height, root length, biomass accumulation, chlorophyll content, pod number, and seed yield following *Glomus* inoculation (Berruti et al., 2016; Smith & Read, 2008).

Field studies under semi-arid tropical conditions show yield increases ranging from 15–35% in low-phosphorus soils due to enhanced nutrient acquisition and physiological performance (Smith & Smith, 2011).

Role in Soil Health and Sustainability

- **Soil Structure and Aggregation**

Extraradical hyphae produce glomalin-related soil proteins that improve soil aggregation and carbon sequestration (Giovannetti et al., 2010). Improved aggregation enhances porosity, aeration, and root penetration capacity.

- **Reduction in Chemical Fertilizer Dependency**

AMF-based biofertilizers can reduce phosphorus fertilizer inputs by 25–50% without compromising yield (Berruti et al., 2016), contributing to cost reduction and environmental protection.

Molecular Insights and Emerging Research

Transcriptomic analyses reveal upregulation of phosphate transporter genes in mycorrhizal roots (Chen et al., 2018). Symbiotic signaling pathways involving Myc factors and SYM genes regulate fungal colonization and nutrient exchange (Smith & Smith, 2011). However, genotype-specific responses require further investigation.

Constraints and Challenges

Field variability, soil-specific performance, cultivar compatibility, inoculum formulation issues, and limited farmer awareness constrain large-scale adoption (Berruti et al., 2016).

Future Prospects

Future agricultural systems must integrate biological inputs such as Glomus within precision nutrient management frameworks (Smith & Read, 2008).

Development of multi-strain consortia and improved formulations will enhance field reliability.

Conclusion

Glomus represents a cornerstone biological input for sustainable soybean production. Through enhanced nutrient uptake, improved nodulation, stress tolerance, and soil health restoration, it significantly contributes to sustainable intensification (Smith & Smith, 2011; Begum et al., 2019). Successful implementation requires standardized inoculum production and interdisciplinary research.

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Green Manuring: A Sustainable Ecofriendly Process for Agriculture

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Abstract

Maharashtra state having regional diversity for cultivation of different crops like cereals, pulses and cash crops. The modern trends in farming to enhance the yield of crop by improving the selected desired traits, hybridization, gene manipulation, and mutation like breeding techniques. These techniques are mostly for increase the yield of crops for tolerance against water scarcity, adverse environment, susceptibility for pastes and salinity of soil. Many crops now cultivated in adverse and off seasonal condition for yield purposes. The economy of farmers and demands in market mostly affects the intensive and continuous cultivation of crops and result on fertility of soil due to poor nutrients content meanwhile crops will be more susceptible to diseases and pastes and produce lower yield.

Crops yield enhancing technique are mostly depends on implementation of chemical or water-soluble fertilizers used in farm as temporary and quick uptake system but it reduces the soil profile data in short duration. Sunnhemp and Dhaincha are most preferred green manure crop plants. The efficiency of fast growth and adaptation for adverse environment are best properties of these crops. High decomposition rate of its biomass helps in short time increase nutrients in soil as green manure. Green manuring improved soil are healthy, enriched biota and fertile that help to increase seasonal crops yield.

Keywords: Manure, hybridization, environment, nutrient, decomposition etc.

Introduction

Agriculture is the backbone of Maharashtra state economy, about 17.43 million hectares area is under cultivation. The state having high diversity related with agro-climatic zone and crop cultivation. The floristic regions of Maharashtra having climatic and regional adaptability of crops that suitable for specific crops growth and yield production. It is a significant state for cultivation of cash crops, oil seeds, cereals, pulses and fruit crops. The high-tech agricultural policies in farming show more advantages of economy but simultaneously results in drawbacks for soil profile. The crucial nutritional security depends on agriculture but the economy empowerment of farmers depends on its agriculture land so fertility of soil plays important role in agriculture.

Green manuring is technique best for organic farming technique utilized to improve soil fertility. Advanced farming and increased high breed crops cultivation for higher yield of crops that results on nutritional reduction of soil so there is a need of to maintain the fertility of soil by ecofriendly techniques that improve the soil nutrition. Organic content in soil maintains long lasting fertility because of addition of organic contents. Green manure helps to improves soil aeration that increases water holding capacity and moisture retention. The organic content improves microbial flora of bacteria, michorrhizal fungi that transform nitrogen, carbon, phosphorus and sulphur as well as water and nutrient uptakes in plants. Microbial activity helps to create stable soil aggregates, enhance water infiltration and protecting against erosion.

Modern Farming and Its Impact of Soil Fertility

- **Hybrid Crops Cultivation:** Hybridization is technique for improving agricultural sustainability and increasing farmer's income through higher productivity. The offspring with superior traits like higher yield, fast growth and environmental stress resistance varieties mostly cultivated now a day, which completely stress on soil nutritional factors. The hybrid crops are fast growing so vigorous absorption of nutrients with water takes place for its growth and development.
- **Intensive Farming and Rapid crop cultivation:** The continuous cultivation of single crop for high profit and quick returns for small–scale farmers generally affected by this process, it reduces the soil fertility and due to that field crop generation by generation reduces the yield and susceptible for pest and reduces soil nutrients.
- **Irrigation Systems:** Excessive irrigation can lead to waterlogging and soil salinization, making the land infertile. The degraded soil becomes uncultivable over time and becomes barren.
- **Soil Pollution in Agriculture:** For yield enhancement of crop utilization of excessive synthetic fertilizers, pesticides, and manures it reduces soil fertility disrupts ecosystems and compromises food safety. This fertilizer results in accumulation of synthetic chemicals, breaking high concentrations of heavy metals like arsenic, lead and mercury that causes hazards to crop plants.
- **Field Cultivation Practices:** Use of heavy machinery led to soil compaction, erosion and reduction of vital organic matter, making the land less

productive.

- **Off Season Crop Cultivation:** The cereals, fruits and vegetables are cultivated for mostly food purposes which having market demands in short period. This crop reduces fertility of soil in short time due to fast growth of crop in controlled condition.
- **Polyhouse Farming:** This developed and protected cultivation agricultural technique using UV stabilized plastic structure to control environmental factors like temperature, humidity and light. It is mostly developed for off-season production of high value crops like vegetables and fruits with multiple time higher yields than the traditional farming but it requires more nutritional factors in soil.

Most Beneficial Green Manure Crops

Sunnhemp and Dhaincha crops are leguminous root nodule forming plants valuable for green manure purpose in all kind of soil for all season. These crops having some basic important properties that shows best quality green manure. Both the plants show fast growth with high biomass productivity and high rate of root nodulation than other plants. These plants are less susceptibility to pathogen and resistance to climatic changes.

These crop shows advantages like easy for cultivation because of high germination rate and growth. These crops grow in all types of soils and easy for incorporation. After incorporation its decomposition rate maximum than other litter. It improves soil fertility for long duration which gives better yield of crops. The biomass contents with alkaloids that prevent root knot nematodes. It also helps from heavy rain fall and heat intensity in dryness which prevent soil erosion.

The cultivation of green manure crops is best practice for sustainable and healthy soil texture. It gives better yield and quality of crops in every stage of growth. It gives natural nutritional balancing in crop products and healthy for human and livestock population and ecosystem.

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Infertility of Agricultural Land

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Abstract

Agriculture is the backbone of India's economy. Over half of the population relies on farming, but the agricultural land is becoming infertile day by day, and crop production is steadily decreasing. The major issue of soil salinization is increasing across the country and is being felt more in the black deep soil belts. After the Green Revolution, radical changes occurred in the agricultural sector; however, its adverse effects are now becoming evident, as crops and the environment are being negatively affected in the long term. Industrial effluents contaminating water sources, improper irrigation practices, and excessive use of fertilizers and pesticides are rapidly transforming soil into saline, sodic, and saline-sodic conditions. The study is based on the main idea of combining traditional knowledge with modern bioremediation, and a way can be found to solve the problem of salinization. The areas of Sambhajinagar (Aurangabad), Ahilyanagar (Ahmednagar), Pune, Satara, Sangli, and Nashik, which have deep black soil and are mostly salt-affected soils. It aims to find solutions to this growing problem by addressing land degradation and restoring it to cultivable condition with the use of effective halophytic microorganisms. The initiatives align with the government of India's policy to transition 50% of agriculture to organic farming by 2030, ensuring sufficient food for future generations.

Keywords: Agriculture, Soil, Salinization, Halophyte.

Introduction

One of the biggest threats to the world's food security is soil infertility and land degradation. A significant amount of the world's agricultural land is obstructed by contamination, erosion, nutrient imbalance, and salinization, according to worldwide evaluations conducted by the Food and Agriculture Organization. The issue is getting worse in semi-arid and heavily farmed areas because of chemical-intensive farming approaches, industrial development, and unsustainable irrigation. Nearly half of India's population is directly or indirectly supported by agriculture. However, there have been unforeseen ecological repercussions as a result of the agriculture sector's rapid development since the Green Revolution. Soil degradation has been caused by a number of factors, including excessive groundwater extraction, canal irrigation without adequate drainage, intensive fertilizer and pesticide use, and growing industrial zones. Waterlogging and secondary salinization are becoming the main productivity barriers in many irrigated regions. The Indian state of Maharashtra is a prime example of these changes. High-value agriculture has benefited from Maharashtra's agroclimatic diversity, which ranges from semi-arid plateaus to irrigated sugarcane belts. Water tables have increased in places where sugarcane is grown. Salinity and sodicity are the results of evaporation, which concentrates salts in the root zone. Heavy metals and other harmful elements are introduced into agricultural soils by polluted rivers that transport industrial trash. These elements ultimately lower crop yields, raise input costs, and reduce soil productivity. There are serious economic impacts. Farmers are forced to raise fertilizer dosages or switch to more expensive soil additions like gypsum as a result of declining yields. A vicious cycle of growing production costs and falling returns is therefore produced. Rural livelihoods are directly impacted by the cost of land reclamation and failing soil health. The Indian government has encouraged organic and sustainable agriculture in appreciation of these problems.

Soil Toxic Conversion

- **Urban and Industrial Pollution**

Raw or partially treated wastewater has been discarded into rivers and streams as a result of the rapid industrialization in and around Pune, Nashik, and Sambhajinagar. When contaminated water is used to irrigate soils, heavy metals, including lead, chromium, and cadmium, build up. Detergents, microplastics, and pharmaceutical residues are further introduced by urban wastewater used for agriculture. These pollutants damage microbial populations, change the pH and EC of the soil, and collapse the enzymatic processes necessary for the cycling of nutrients. Soils change finished time from biologically active systems to substrates under chemical stress. Through the food chain, toxic buildup not only lowers fertility but also presents health hazards.

- **Soil Irrigation Management**

Secondary salinization in the districts of Sangli and Ahilyanagar is mostly caused by improper irrigation. Waterlogging results from canal irrigation without proper drainage. High rates of evaporation pull salts to the surface in arid and semi-arid areas. In the lack of subsurface drainage, soil permeability is decreased, clay particles are dispersed, and sodicity is accelerated.

This problem has arisen due to overuse of groundwater. With the degradation of aquatic organisms, the amount of dissolved salts increases. Frequent watering with saline groundwater gradually toxifies the soil. An increase in electrical conductivity (EC) and exchangeable sodium percentage (ESP) adversely affects root development and nutrient utilization.

- **Chemical Overload and Imbalance**

The excessive use of chemical fertilizers, pesticides, fungicides, and herbicides disturbs soil nutrient balance. Continuous cropping increases nutrient mining. Beneficial microbes decline under chemical stress.

Destructive Effects of Soil Infertility

- **Physical Degradation**

Salinity and sodicity reduce the structure of the soil, causing dispersion. Soil aggregation breaks down, which leads to compacting, crusting, and reduced infiltration. Water accumulates on the surface, increasing the risk of erosion.

- **Biological Collapse**

Toxic pollution and excessive salinity reduce microbial biomass and enzymatic activity. Beneficial fungi and earthworms are rapidly reduced.

- **Decrease in Crop Production**

Salinity imposes osmotic stress on plants, limiting water uptake. Sodium toxicity disrupts cellular metabolism and photosynthesis. Crops exhibit stunted growth, chlorosis, and reduced grain filling. In sugarcane fields of western Maharashtra, yield reductions of 20–40% have been reported under moderate salinity conditions. Wheat, pulses, and horticultural crops also show sensitivity to elevated soil EC.

- **Economic and Social Impacts**

Reduced soil productivity directly affects farmers’ incomes. Increased cost on fertilizers, soil amendments, and irrigation deepens indebtedness. Marginal farmers in Satara and Sangli face livelihood insecurity, prompting migration to urban areas like Pune. Social stress, land abandonment, and reduced agricultural employment become secondary consequences of soil infertility.

Remediation Strategies for Revival Infertile Lands

- **Water Management**

Improved irrigation strategies are important. Implementation of drip and sprinkler systems and salt buildup. Subsurface drainage networks in canal areas help lower water tables. Periodic leaching with good-quality water blooms excess salts from the root zone. Conjunctive use of surface and groundwater optimizes salinity control. Watershed development programs in Maharashtra highlight rainwater harvesting and recharge structures to restore hydrological balance.

- **Revival of Organic Matter**

Increasing soil organic carbon is central to restoring fertility. Application of organic manure, compost, green manure crops, and crop residues enhances aggregation and microbial activity. Biofertilizers and vermicompost contribute to nutrient cycling and reduce chemical dependency. Government-supported organic clusters under PKVY encourage farmers to adopt natural farming inputs such as jeevamrut and botanical extracts. Enhanced organic matter improves cation exchange capacity and buffers salinity stress.

- **Farmer Employment and Capacity-Building Programs**
    - Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) supports land development and drainage construction.
    - Training programs by agricultural universities and Krishi Vigyan Kendras (KVKs) equip farmers with knowledge on soil testing, balanced fertilization, and sustainable irrigation practices.

Bioremediation with Halotolerant and Halophilic Microorganisms

Halotolerant and halophilic microorganisms can survive in saline environments. They promote plant growth through:

- Production of phytohormones (IAA, gibberellins)
- Solubilization of phosphorus and potassium
- Nitrogen fixation
- Synthesis of osmoprotectants

The salt-tolerant plant growth-promoting rhizobacteria (PGPR) improves root development and nutrient uptake. These microbes reduce salinity and enhance crop resilience. Microbial consortia with organic amendments accelerate soil rehabilitation.

- **Social and Government Policy Reforms**

Organic market linkages, minimum support prices for sustainably grown crops, and subsidies for micro-irrigation can drive adoption.

Collaboration among state agencies, farmer producer organizations, and research institutions can create district-level soil restoration models.

Conclusion

Agricultural land infertility in Maharashtra reflects a broader global crisis of soil degradation. In districts such as Ahilyanagar, Sambhajinagar, Nashik, Pune, Sangli, and Satara, waterlogging, industrial pollution, excessive irrigation, and chemical fertilizers over use are driving salinization and toxicity.

Integrated remediation strategies combining improved water management, organic matter restoration, employment-linked land development, microbial bioremediation, and supportive government policies offer a pathway toward sustainable recovery. Environmental safeguards can help restore soil health, secure farmer livelihoods, and ensure long-term agricultural resilience in Maharashtra and across India.

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Biotechnological Approaches to Enhance Fungal Disease Resistance in Papaya (*Carica papaya* L.) Under Climate Change Scenarios

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Abstract

A valuable tropical fruit is the papaya *(Carica papaya* L.) extensively cultivated across Asia, Latin America, and Africa for its nutritional and economic importance. Its productivity is significantly limited by destructive fungal diseases such as anthracnose, Fusarium wilt, stem rot, and root rot. Climate change marked by rising temperatures, irregular rainfall, and elevated atmospheric CO_2 has intensified pathogen virulence, expanded their distribution, and increased host vulnerability. Conventional control measures, including fungicides and cultural practices, are proving insufficient under fluctuating environmental conditions. This chapter examines advanced biotechnological strategies, including molecular diagnostics, marker-assisted breeding, genetic engineering, CRISPR/Cas genome editing, omics technologies, tissue culture, and microbiome engineering, to develop climate-resilient, disease-resistant papaya cultivars for sustainable production systems.

Keywords: Papaya (*Carica papaya* L.); Fungal diseases; Climate change; Disease resistance; CRISPR/Cas genome editing; Climate-smart agriculture.

Introduction

In tropical and subtropical areas, papaya (*Carica papaya* L.) is one of the most significant fruit crops because of its nutritional, therapeutic, and commercial importance. Antioxidants, the proteolytic enzyme papain, and vitamins A and C are all abundant in it. India, Brazil, Mexico, Indonesia, and Nigeria are among the major producing nations. Despite its economic significance, papaya production is highly vulnerable to fungal diseases, which reduce yield, fruit quality, and export potential. Climate change has emerged as a critical factor influencing plant disease dynamics. Increased temperature, humidity fluctuations, and extreme weather events create favourable conditions for fungal growth and disease proliferation. Therefore, there is an urgent need to develop durable, climate-resilient disease resistance in papaya through advanced biotechnological interventions.

Major Fungal Diseases of Papaya

Papaya is highly susceptible to several destructive fungal pathogens that significantly reduce yield and fruit quality. Colletotrichum gloeosporioides, which causes anthracnose, is a serious post-harvest illness. while Fusarium wilt, caused by Fusarium solani, severely affects plant survival and field productivity. *Alternaria alternata* is also an important pathogen associated with fruit spot and quality deterioration (Woudenberg et al., 2015). In addition to these, papaya is affected by stem rot caused by *Phytophthora palmivora*, damping-off caused by *Pythium spp*. and *Rhizoctonia spp*., and powdery mildew caused by *Oidium caricae*. These pathogens collectively contribute to significant economic losses in papaya cultivation.

Impact of Climate Change on Papaya–Fungal Interactions

- **Temperature Rise**

Increasing temperatures accelerate fungal growth, shorten incubation periods, and enhance sporulation, resulting in rapid disease cycles and severe outbreaks.

- **Elevated CO_2**

Higher atmospheric CO_2 levels alter plant carbon–nitrogen balance and metabolic processes, influencing defence gene expression (Eastburn et al., 2011).

- **Irregular Rainfall**

Frequent rainfall and prolonged humidity promote spore germination, infection, and rapid disease spread. Extended leaf wetness significantly increases epidemic intensity.

- **Climate-Induced Abiotic Stress**:

Drought, flooding, and heat stress reduce plant immunity, emphasizing the need for climate-resilient, disease-resistant papaya cultivars.

Limitations of Conventional Management in Papaya Fungal Disease Control

Conventional management of fungal diseases in papaya largely depends on chemical fungicides, sanitation, crop rotation, biological control agents, and traditional breeding. While these methods can temporarily suppress disease incidence, their sustainability is increasingly challenged under climate change. Repeated and indiscriminate fungicide use exerts strong selection pressure on

Fungal pathogens such as Colletotrichum spp. and Fusarium spp., resulting in the emergence of resistant strains and reduced chemical efficacy (Lucas et al., 2015). Excessive fungicide application also raises food safety and ecological concerns, including residue accumulation, soil and water contamination, and adverse effects on beneficial organisms. Climate variability further reduces reliability, as heavy rainfall washes off chemicals and high humidity promotes rapid reinfection. Soil-borne pathogens persist despite crop rotation due to durable survival structures (Garrett et al., 2016).

Molecular Diagnostics and Early Detection

For papaya infections to be effectively managed, early and accurate detection of fungal pathogens is essential, especially in climate change scenarios where outbreaks can spread quickly. Compared to conventional culture-based identification techniques, molecular diagnostic technologies provide higher sensitivity, specificity, and speed, allowing for prompt intervention.

- **PCR and qPCR**

Pathogen-specific DNA sequences can be precisely detected using polymerase chain reaction (PCR) even before symptoms become apparent. Quantitative PCR (qPCR) further quantifies pathogen load, allowing assessment of disease severity, monitoring of infection dynamics, and evaluation of treatment effectiveness (Schaad et al., 2003).

- **Loop-Mediated Isothermal Amplification (LAMP)**

LAMP is a swift, economical method that amplifies DNA under constant temperature conditions. Its simplicity and minimal equipment requirement make it highly suitable for on-site, field-level diagnostics in papaya-growing regions.

- **Next-Generation Sequencing (NGS)**

NGS facilitates whole genome sequencing and detailed characterization of pathogen populations. It enables identification of virulence genes, genetic variability, and emerging strains, supporting disease surveillance and resistance breeding programs. Together, these molecular tools strengthen early warning systems and enhance precision disease management strategies.

Molecular Basis of Disease Resistance:

- **Pattern-Triggered Immunity (PTI**

PPTI is initiated when plant receptors recognize conserved pathogen-associated molecular patterns (PAMPs). This triggers basal defence responses such as cell wall fortification, production of antimicrobial compounds, and activation of defence-related genes.

- **Effector-Triggered Immunity (ETI)**

ETI is activated when specific resistance (R) genes detect pathogen-secreted effector proteins. In order to stop the spread of the virus, this greater reaction frequently results in localized cell death (hypersensitive response). These immunological responses are controlled by defense signaling pathways that are regulated by salicylic acid (SA), jasmonic acid (JA), and ethylene (ET).

Marker-Assisted Selection and Molecular Breeding

Marker-assisted selection (MAS) enhances resistance breeding in papaya by enabling early and precise identification of fungal disease–resistant genotypes using DNA markers. Tools such as SSR and SNP markers, along with QTL mapping and genomic selection, facilitate accurate introgression of resistance traits and significantly shorten breeding cycles. These molecular approaches reduce environmental influence on selection and accelerate the development of Climate-adaptable cultivars

Genetic Engineering Approaches

The introduction of resistance qualities beyond papaya's inherent genetic variability is made possible by genetic engineering. Transgenic strategies incorporating antifungal genes, such as chitinases and β-1,3-glucanases, strengthen host defence by degrading fungal cell walls. RNA interference (RNAi) technology allows targeted silencing of essential fungal virulence genes, reducing pathogen infectivity. Host-Induced Gene Silencing (HIGS), an advanced RNAi-based approach, involves the production of double-stranded RNA within the plant that specifically suppresses pathogen gene expression during infection.

CRISPR/Cas Genome Editing

CRISPR/Cas genome editing offers a highly precise and efficient method for improving fungal disease resistance in papaya. By knocking out susceptibility (S) genes or enhancing endogenous defence-related genes, this technology strengthens plant immunity (Borrelli et al., 2018; Zaidi et al., 2018). Pyramiding resistance features is made possible by the simultaneous alteration of many genes by multiplex genome editing. CRISPR-edited plants are a viable strategy for improving climate-adaptive crops since they may encounter less regulatory obstacles in some areas than standard transgenic methods.

Omics Approaches

Omics technologies provide comprehensive insights into host–pathogen interactions. Genomics identifies resistance gene families and pathogen virulence determinants through whole-genome sequencing. Transcriptomics analyses gene expression patterns under fungal infection and environmental stress, revealing key regulatory pathways (Wang et al., 2010). Proteomics and metabolomics further identify defence-related proteins and antifungal metabolites activated during infection.

Tissue Culture and In Vitro Approaches

Plant tissue culture methods ensure consistent orchard establishment by facilitating the quick multiplication of disease-free planting material. Somaclonal variation generated during in vitro culture may produce novel resistant variants. In vitro screening using pathogen toxins or culture filtrates facilitates rapid identification of tolerant genotypes. Cryopreservation methods preserve elite resistant germplasm for long-term breeding programs.

Microbiome Engineering and Biological Synergy

Harnessing beneficial microorganisms such as endophytes and plant growth-promoting rhizobacteria (PGPR) enhances induced systemic resistance and improves plant performance under stress conditions. Engineering climate-adapted microbial consortia strengthens natural defense mechanisms and provides sustainable protection against fungal pathogens.

Integrated Climate-Smart Disease Management

A holistic approach combining biotechnology with agroecological practices ensures durable resistance. Key components include deployment of resistant cultivars, precision agriculture and digital disease forecasting tools, reduced reliance on chemical fungicides, and sustainable soil health management. Integration of molecular breeding with climate modeling enhances early warning systems and resilience.

Conclusion

Fungal diseases increasingly threaten papaya production, especially as climate change enhances pathogen survival, spread, and host vulnerability. Traditional control measures alone are inadequate to manage these evolving risks. Advanced biotechnological tools such as marker-assisted selection, molecular diagnostics, CRISPR based genome editing, omics approaches, genetic engineering, tissue culture, and microbiome engineering provide precise and sustainable alternatives. Integrating these innovations within climate-smart agricultural systems will support the development of resilient, high-yielding papaya cultivars. Strengthened research efforts, supportive regulatory frameworks, and farmer participation are crucial for successful implementation.

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Agricultural Innovation for Sustainable Development

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Abstract

Agriculture in the twenty-first century faces major challenges including rapid population growth, climate change, resource depletion, and rising food and nutritional demands. Sustainable development increasingly depends on innovation in agricultural science. This includes the development and adoption of advanced technologies such as precision farming, biotechnology, automation, biofertilizers, and climate-resilient practices. Effective implementation also relies on strong extension services, research, education, and supportive institutional frameworks. While innovation offers significant opportunities to enhance productivity, efficiency, and sustainability, barriers to adoption remain. Addressing these challenges can transform traditional agriculture into a modern, resilient system capable of ensuring global food security and supporting broader development goals.

Introduction

Agriculture is a dynamic and evolving science essential for ensuring food security, improving rural livelihoods, and supporting national economic development. However, traditional farming practices are increasingly insufficient to meet growing demands due to population pressure, climate change, resource degradation, and the need for nutrient-rich food (Godfray et al., 2010). Consequently, innovation in agricultural research has become a key driver of sustainable development. Agricultural science focuses on developing, adapting, and applying new knowledge, technologies, and practices to enhance productivity, efficiency, and resilience.

It encompasses biological innovations such as improved crop varieties and bio-inputs, technological advancements like precision farming and mechanization, digital tools for decision-making, and institutional approaches that strengthen farmer participation and market access. These innovations contribute to higher farm incomes, improved climate resilience, and sustainable resource use. Agricultural innovation refers to the application of new technologies, systems, and strategies that improve the sustainability and productivity of farming systems (Pretty et al., 2011).

Globally, governments, academic institutions, and organizations such as the Food and Agriculture Organization and the United Nations emphasize innovation-driven approaches. Thus, agricultural innovation is crucial for transforming traditional agriculture into a modern, efficient, and sustainable sector.

Concept and Scope of Agricultural Innovation

In agricultural research, innovation is the creation, improvement, and application of new approaches, tools, and techniques that enhance agricultural output and long-term sustainability (Rogers, 2003). It includes developments in farming methods, crop and livestock management, value chain enhancements, policy formulation, and knowledge-sharing platforms in addition to technology breakthroughs (FAO, 2018). Agricultural innovation encompasses the following areas:

- Improvement of crops and livestock
- Water and soil management system
- A system for controlling diseases and pests
- Automation and mechanization of farms
- Precision and digital farming systems

To promote inclusive and sustainable agricultural development worldwide, climate-smart and sustainable agricultural innovation systems involve a variety of stakeholders, including farmers, researchers, extension agencies, agribusinesses, policymakers, and organizations such as the Food and Agriculture Organization.

Various Innovations in Agriculture

- **Precision Agriculture**

Modern technologies such as GPS, remote sensing, drones, and sensors are used in precision agriculture to optimize field-level control. These technologies assist farmers in increasing yields while reducing costs and environmental impacts by more efficiently applying inputs, including water, fertilizer, and insecticides (Wolfert et al., 2017).

- **Farm Mechanization and Automation**

Robotics, automated systems, and modern machinery have greatly decreased the need for labour and increased productivity. Innovations such as robotic harvesters, autonomous tractors, and intelligent irrigation systems are especially helpful in managing labour shortages and improving operational timeliness (Pingali, 2012).

- **Crop Improvement and Biotechnology**

Due to advances in molecular biology, genetic engineering, and plant breeding, high-yielding, pest-resistant, and stress-tolerant crop varieties have been developed. Thanks to techniques such as genome editing and marker-assisted selection, breeding has become more accurate and efficient (Singh & Singh, 2017).

- **Biofertilizers and Biopesticides**

An important development in sustainable agriculture is the application of biopesticides, mycorrhizal fungi, and biofertilizers. These biological inputs support environmentally friendly farming systems by increasing soil fertility, promoting plant growth, and reducing reliance on chemical pesticides and fertilizers (Altieri et al., 2015).

- **Digital Innovations and Smart Agriculture**

Digital agriculture integrates information and communication technology (ICT) with farming operations. Using mobile applications, artificial intelligence, big data analytics, and decision-support systems, farmers may make informed choices regarding crop selection, pest control, and market access (Wolfert et al., 2017). Furthermore, smallholder farmers are empowered and farm profitability is increased by smart agricultural systems that provide real-time weather forecasts, soil health monitoring, and price information (FAO, 2018).

- **Climate-Smart Agricultural Innovations**

Climate change is making droughts, floods, and other extreme weather events more frequent, posing a serious threat to agricultural productivity. Climate-smart agriculture focuses on innovations that improve resilience, reduce greenhouse gas emissions, and promote production (FAO, 2013).

These include drought-tolerant cultivars, conservation agriculture, agroforestry systems, and water-efficient irrigation techniques. By emphasizing the importance of innovation in achieving environmental sustainability and food security, international initiatives aligned with the United Nations Sustainable Development Goals promote these practices (United Nations, 2015).

Institutional and Social Responsibilities

Institutional and social innovations such as farmer-producer organizations, cooperative and contract farming, and participatory research enhance access to resources, markets, and knowledge (Rogers, 2003). Extension services and capacity-building initiatives by organizations like ICAR support effective implementation (ICAR, 2020). Universities and research centers play a key role in developing and disseminating innovations through interdisciplinary research and technology transfer (Swaminathan, 2018). Collaboration among academia, industry, and farming communities accelerates innovation and ensures practical relevance (FAO, 2018).

Challenges in Agricultural Innovation

Despite advancements, several barriers limit the adoption of agricultural innovations, including small landholdings, poor infrastructure, low awareness, limited access to finance, and socioeconomic constraints. Bridging the gap between innovation and practical application remains a key challenge, especially in developing countries. Future agricultural research must integrate technological, biological, and social innovations to build resilient and sustainable systems. Emphasis on digital transformation, climate resilience, and farmer-centered approaches will shape future growth. Overall, innovation plays a vital role in enhancing productivity, sustainability, and rural development, while ensuring food security and conserving natural resources for future generations.

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The Power of Biological Agents: Improving Crops for Sustainable Agriculture

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Introduction

For recent some years the modern agriculture arises as a part of green revolution which is fuelled by Synthetic chemistry. It helped humans to develop the art of scaling up food production to meet the demands of an increasing global population. But this success came with some environmental concerns such as soil pollution water pollution through persistent leaching of toxins into precious water tables, & negative effects on animal & human health. To avoid consequences and to secure future of upcoming generation the shift from chemical dominance to biological cooperation become a need of time. This transition to sustainable agriculture is no longer a niche preference; it is a global necessity.

Sustainable agricultural mainly relies on biofertilizers and biopesticides—living microbial products that enhance soil fertility and protect crops without the toxic residues associated with agrochemicals. These biological inputs are core components of Integrated Nutrient Management (INM) and Integrated Pest Management (IPM), offering a scalable pathway toward regenerative farming.

Biofertilizers

Biofertilizers Enhance nutrient uptake by harnessing the natural power of microbes, such as nitrogen-fixing bacteria and mycorrhizal fungi. Biofertilizers contain dormant or active microbial cells that colonize the plant rhizosphere, converting unavailable soil nutrients into forms plants can readily absorb. Following are some biofertilizers

- **Nitrogen-Fixing Bacteria:** Convert atmospheric nitrogen into ammonia.
- **Symbiotic Bacteria:** Rhizobium forms root nodules in legumes (e.g., peas, soybeans), significantly reducing the need for urea.
- **Free-Living & Associative Bacteria:** *Azotobacter* and *Azospirillum* enrich the soil for non-legumes like maize, rice, and wheat.

- **Cyanobacteria (Blue green algae):** *Anabaena* and *Nostoc* are vital for nitrogen enrichment in paddy (rice) fields.
- **Phosphate-Solubilizing Microorganisms (PSM):** Microbes like *Bacillus megaterium* and *Pseudomonas striata* secrete organic acids (e.g., gluconic, citric) that dissolve insoluble phosphate compounds, making them bioavailable for root development and flowering.
- **Potassium & Micronutrient Mobilizers:** Bacteria such as *Frateuria aurantia* (potassium) and various *Bacillus species* (zinc, iron, sulfur) mobilize these elements, improving grain quality and plant disease resistance.
- **Mycorrhizal Fungi:** Arbuscular Mycorrhizal Fungi (AMF), such as *Glomus species*, extend the root network through hyphae, vastly increasing surface area for water and phosphorus absorption.

Biopesticides: Eco-Friendly Pest Management

Biopesticides utilize natural mechanisms such as competition, predation, and toxin production to manage pests with high specificity, protecting beneficial insects like pollinators. Following are some types of biopesticides

1. **Microbial Biopesticides**

- **Bacterial:** *Bacillus thuringiensis* (Bt) is the most widely used, producing toxins that specifically target lepidopteran larvae.
- **Fungal:** *Trichoderma species* act as antagonists against soil-borne pathogens like Fusarium and Rhizoctonia through competition for space and nutrients.
- **Viral:** *Baculoviruses* (e.g., Granulovirus) are used for highly targeted control of specific agricultural caterpillars in crops like soybean and fruit trees.

2. **Mechanisms of Action**

- **Antibiosis:** Production of antimicrobial metabolites (e.g., hydrogen cyanide or antibiotics) that inhibit pathogen growth.
- **Induced Systemic Resistance (ISR):** Microbes stimulate the plant's own defence systems, making it more resilient to future attacks.
- **Competition:** Beneficial microbes outcompete pathogens for limited rhizospheric nutrients and space.

3. **Benefits and Future Outlook**

- **Environmental & Economic Value:** Bio-inputs restore soil health, reduce greenhouse gas emissions, and can be up to 81% more profitable for farmers due to lower input costs and premium prices for organic produce.
- **Challenges:** Key hurdles include a limited shelf life (viability can drop 15–30% monthly at ambient temperatures), sensitivity to UV and heat, and the need for specialized storage.
- **Market Growth:** The global biofertilizer market is projected to reach

approximately \$8.09 billion by 2034, driven by government subsidies and a consumer shift toward residue-free food.

Conclusion

Shifting of agriculture from chemical-heavy farming to biological cooperation is no longer just an idea, it is a necessity for our planet’s survival. By using nature’s own tools, like biofertilizers and biopesticides, we can heal our soil, keep our water clean, and grow food that is safe for everyone.

While we still face challenges, such as making these living products last longer on the shelf, the benefits are clear. They help farmers save money, protect helpful insects like bees, and create a farming system that can last for generations. As technology improves and more farmers make the switch, these tiny microbes will play a giant role in feeding the world safely and sustainably.

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Climate Change and the Green Technology Revolution

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Introduction

Long-term changes in Earth's climate, such as variations in temperature, precipitation, and weather patterns, are referred to as climate change. Although these changes can happen naturally, human actions like burning fossil fuels, deforestation, and industrialization have been the main causes of them in recent years. Fuels and fossil fuels are utilized to continuously produce power. Burning these fuels releases gases including carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which trap heat in the atmosphere and cause "global warming" (Nikita Saklani & Ashli Khurana, 2019).

Because it destroys the ecology, this climate change is detrimental rather than advantageous. The environment is being negatively impacted by human activity, which is causing major climatic changes that have a variety of effects on life. In the upcoming years, living on Earth may grow more challenging and the situation may become unmanageable if effective measures are not established to meet these changes. (Kabir Muhammad, 2023)

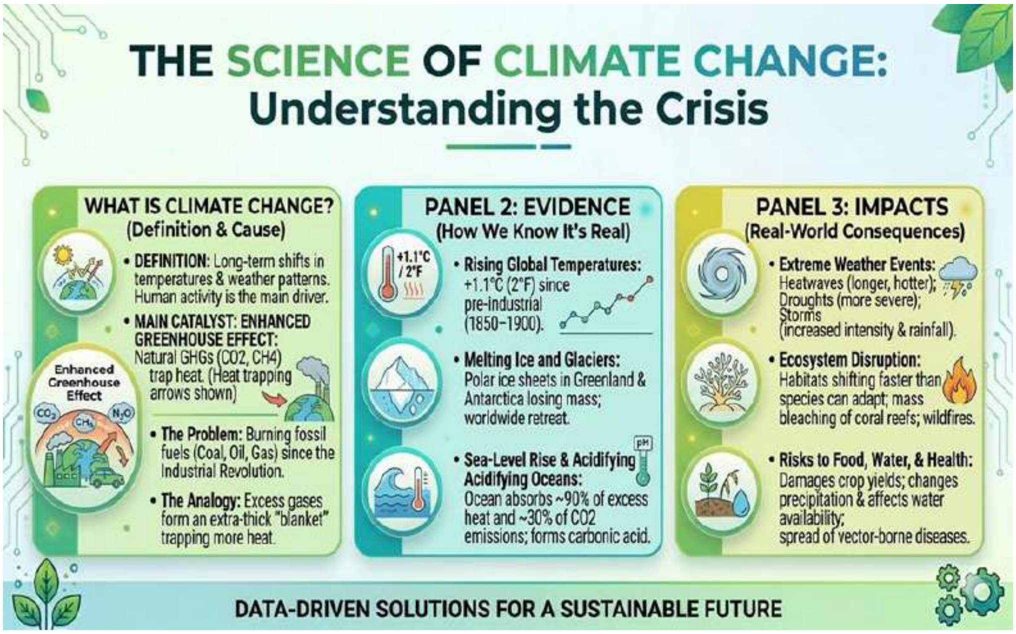
The creation and use of goods, machinery, and systems intended to preserve the environment, lessen human influence, and conserve resources is referred to as "green technology" (Genentech). It encompasses sustainable agriculture, waste management, energy efficiency, and renewable energy. In response to these issues, governments, businesses, and academics are concentrating more on green technologies as a crucial means of reducing climate change and advancing sustainable development.

Human Activities Contributing Climate Including

- The burning of fossil fuels, including natural gas, coal, and oil.
- Urbanization and deforestation.
- Transportation and industrialization.
- Farming methods

These actions accelerate the release of carbon dioxide and other chemicals into the atmosphere, upsetting the normal carbon cycle and contributing to climate change and global warming in recent years. Climate change's effects the environment; ecosystem, economy, and human health are all impacted by climate change. Significant effects include

- The world's temperature is rising.
- Severe weather conditions.
- Sea level rise, ice melting, and increased coastal flooding.
- A shift in the quantity, timing, and distribution of precipitation.
- Disruption of marine and other coastal ecosystems
- Loss of biodiversity and extinction of plant and animal species.



THE SCIENCE OF CLIMATE CHANGE: Understanding the Crisis

WHAT IS CLIMATE CHANGE? (Definition & Cause)

- **DEFINITION:** Long-term shifts in temperatures & weather patterns. Human activity is the main driver.
- **MAIN CATALYST: ENHANCED GREENHOUSE EFFECT:** Natural GHGs (CO2, CH4) trap heat. (Heat trapping arrows shown)
- **The Problem:** Burning fossil fuels (Coal, Oil, Gas) since the Industrial Revolution.
- **The Analogy:** Excess gases form an extra-thick "blanket" trapping more heat.

PANEL 2: EVIDENCE (How We Know It's Real)

- **Rising Global Temperatures:** +1.1°C (2°F) since pre-industrial (1850–1900).
- **Melting Ice and Glaciers:** Polar ice sheets in Greenland & Antarctica losing mass; worldwide retreat.
- **Sea-Level Rise & Acidifying Acidifying Oceans:** Ocean absorbs ~90% of excess heat and ~30% of CO2 emissions; forms carbonic acid.

PANEL 3: IMPACTS (Real-World Consequences)

- **Extreme Weather Events:** Heatwaves (longer, hotter); Droughts (more severe); Storms (increased intensity & rainfall).
- **Ecosystem Disruption:** Habitats shifting faster than species can adapt; mass bleaching of coral reefs; wildfires.
- **Risks to Food, Water, & Health:** Damages crop yields; changes precipitation & affects water availability; spread of vector-borne diseases.

DATA-DRIVEN SOLUTIONS FOR A SUSTAINABLE FUTURE

Green technology

Technology is the use of knowledge to solve real-world problems. Green technologies are interdisciplinary, lessen the influence of humans on the environment, and encourage sustainable growth. The main requirements for green technology are social justice, economic viability, and environmental sustainability. Soni (2015). Future generations' entitlement to a high-quality environment is safeguarded by the ecological dimension of sustainable development, which emphasizes a controlled attitude to ecosystems and "green" technologies as the foundation for creative growth.

KEY CATEGORIES OF GREEN TECHNOLOGY: INNOVATING FOR A SUSTAINABLE FUTURE

RENEWABLE ENERGY GENERATION
- Solar Power (PV Cells)
- Wind Energy (Onshore/Offshore)
- Hydro & Geothermal

SUSTAINABLE TRANSPORTATION
- Electric Vehicles (EVs)
- Hydrogen Fuel Cells
- Micromobility (E-bikes, scooters)

GREEN BUILDING & SMART CITIES
- Energy-Efficient HVAC & Smart Thermostats
- Smart Grids for Optimal Distribution
- Sustainable Building

CIRCULAR ECONOMY & WASTE MANAGEMENT
- Advanced Recycling Systems
- Waste-to-Energy (Bioenergy)
- Biodegradable & Plant-based Plastics

CARBON CAPTURE & STORAGE (CCS)
- Direct Air Capture (DAC)
- Point-Source Carbon Capture
- Industrial CO2 Sequestration

DRIVING THE TRANSITION TO A CLEANER PLANET

Types of Green Technologies

Renewable Energy Technologies

Clean alternatives to fossil fuels are provided by renewable energy sources like solar, wind, hydroelectric, and geothermal power. These energy systems contribute significantly to lowering dependency on conventional energy sources and produce minimal or no greenhouse gas emissions.

Electric Vehicles (EVs)

Electric vehicles significantly reduce transportation-related carbon emissions because they run on electricity rather than fossil fuels. They are crucial in lowering the transportation sector's carbon emission.

Green Buildings

Green buildings focus on improving energy efficiency and lowering environmental damage. They commonly use solar panels, proper insulation, water-saving systems, and sustainable construction materials.

Storage and Capture of Carbon (CCS)

Carbon capture systems help lower the overall carbon footprint by keeping carbon dioxide produced by power stations and industry out of the atmosphere.

Climate-Aware Farming

Climate-smart agriculture promotes ecologically friendly farming methods, boosts output, and assists farmers in reducing emissions while adapting to climate change.

Role of Green Technologies in Combating Climate Change

In order to combat climate change, green technologies are essential since they:

- Reducing greenhouse gas emissions, which includes cutting carbon emissions and air pollutants.
- Encouraging energy efficiency: increasing productivity while reducing energy waste.
- Promoting responsible consumption and renewable alternatives in order to encourage sustainable resource usage.
- Promoting circular economy techniques to cut waste, such as recycling, reusing, and prolonging product lifecycles.
- Enhancing environmental conservation: safeguarding natural habitats, biodiversity, and ecosystems. The development of climate-resilient communities and the reduction of environmental degradation are greatly aided by innovations like energy-efficient transportation, smart grids, and renewable energy systems.

Challenges in Implementing Green Technologies

Adoption of green technologies confronts a number of obstacles notwithstanding their benefits:

- Expensive initial outlay of funds
- Insufficient technological infrastructure in developing countries
- Low awareness and limited technical expertise
- Policy and regulatory barriers
- Dependence on traditional energy systems

Overcoming these challenges requires strong government policies, enhanced international cooperation, and increased investment in research and development. Despite their advantages, the deployment of green technologies encounters several obstacles.

Conclusion

The sustainability of the environment, economic stability, and human well-being are all seriously threatened by climate change. Growing atmospheric concentrations of greenhouse gases have increased global warming and made related environmental issues worse. Green technologies offer workable, empirically supported ways to lower emissions, preserve natural resources, and advance sustainable development. Societies may greatly lessen the effects of climate change and progress toward a more sustainable future by implementing low-emission transportation, renewable energy systems, and ecologically friendly production techniques.

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Fungi as Silent Engineers of Climate Regulation

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Abstract

Climate discourse frequently emphasizes forests, oceans, and atmospheric chemistry, yet the organisms that ultimately determine the fate of most terrestrial carbon are microscopic and often overlooked. Fungi mediate decomposition, regulate nutrient exchange with plants, restructure soils, and influence greenhouse gas production. Through these processes, they act as intermediaries between primary productivity and atmospheric feedback. This chapter critically examines fungal roles in carbon stabilization and release, arguing that climate projections remain incomplete without explicit recognition of fungal functional diversity. Evidence from boreal systems, peatlands, grasslands, and agricultural soils suggests that fungal responses to warming are neither uniform nor linear. In some contexts, fungal activity enhances long-term carbon storage; in others, it accelerates atmospheric carbon return. By integrating ecological mechanisms with recent biogeochemical findings, this chapter positions fungi not as passive decomposers but as dynamic regulators within Earth's climate system.

Keywords: fungal ecology; carbon cycling; soil carbon storage; mycorrhizal symbiosis; greenhouse gas flux; peatland carbon; nitrogen transformations; climate feedback

Rethinking the Role of Fungi in Climate Science

- ### Beyond Decomposition: A Conceptual Shift

For decades, fungi were primarily described as decomposers organisms responsible for recycling dead organic matter. While accurate, that characterization is incomplete. Decomposition is not simply a recycling process; it is a regulatory checkpoint within the global carbon cycle. The rate at which fungi mineralize organic substrates directly determines whether carbon accumulates in soils or re-enters the atmosphere as CO_2.

Recent work on soil microbiomes has emphasized that microbial physiology not just temperature or moisture controls carbon turnover (Jansson & Hofmockel, 2020). This insight complicates earlier climate models that treated soil carbon loss as a straightforward temperature response. Instead, fungal community composition, enzyme production strategies, and nutrient competition emerge as decisive variables.

- **Temperature Sensitivity and Ecological Context**

Experimental warming studies demonstrate that soil carbon losses increase with temperature (Crowther et al., 2016). However, these results are often interpreted as universally applicable. A closer examination reveals variation across ecosystems. In nutrient-poor forests, ectomycorrhizal fungi may suppress saprotrophic activity by competing for nitrogen, indirectly slowing decomposition (Averill et al., 2014). Thus, warming effects are mediated by ecological interactions rather than driven by temperature alone. This nuance is critical if fungal communities shift under climate stress, the direction and magnitude of carbon feedback could change in unexpected ways (Thurner et al., 2024).

Decomposition as a Regulated Process

- **Enzymatic Capabilities and Carbon Fate**

White-rot fungi such as *Phanerochaete chrysosporium* possess oxidative enzymes capable of breaking down lignin, enabling complete mineralization of woody biomass. Brown rot fungi like *Serpula lacrymans*, by contrast, selectively degrade cellulose while modifying lignin residues. These contrasting strategies influence soil chemistry and long-term carbon persistence. The critical point is not merely that fungi decompose biomass, but that they do so selectively. The biochemical pathway employed determines whether carbon is rapidly oxidized or incorporated into more stable soil fractions. This distinction has implications for predicting soil carbon responses under environmental change.

- **Cold Ecosystems and Carbon Storage**

In boreal and Arctic environments, decomposition proceeds slowly. Genera such as *Cortinarius* remain active but at reduced metabolic rates. As a result, organic matter accumulates, forming substantial carbon reservoirs yet warming threatens this equilibrium. Increased enzymatic efficiency under higher temperatures could mobilize centuries of stored carbon (Thurner et al., 2024).

Importantly, not all fungal taxa respond identically to warming. Some exhibit thermal acclimation, while others decline. Therefore, predicting carbon release requires understanding community restructuring, not simply temperature sensitivity.

- **Peatlands: Suppression and Vulnerability**

Peatlands illustrate the consequences of constrained fungal activity. Waterlogged conditions limit oxygen availability, suppressing oxidative enzymes and allowing partially decomposed plant matter to accumulate. However, drainage or drought rapidly reactivates fungal metabolism. The shift from carbon sink to carbon source can occur within relatively short timeframes, highlighting the fragility of these systems.

Mycorrhizal Fungi and Carbon Stabilization

- **Nutrient Competition and Soil Carbon**

Ectomycorrhizal fungi such as *Pisolithus tinctorius* exchange nitrogen for plant-derived carbon. By sequestering nitrogen in fungal biomass, they may limit its availability to saprotrophs, slowing decomposition (Averill et al., 2014). This mechanism sometimes described as the "Gadgil effect" demonstrates how symbiosis can indirectly regulate soil carbon. However, this effect is context-dependent. In nutrient-rich soils, competitive suppression may weaken, reducing the carbon-stabilizing influence of ectomycorrhizal networks. Thus, the climate relevance of mycorrhizae varies across landscapes.

- **Soil Aggregation and Physical Protection**

Arbuscular mycorrhizal fungi, including *Rhizophagus irregularis*, produce glomalin-related proteins that enhance soil aggregation (Rillig et al., 2021). Aggregated soils protect organic matter from rapid microbial attack while often cited as evidence of fungal carbon sequestration, this process should not be idalized. Aggregation delays decomposition but does not prevent it indefinitely long-term outcomes depend on disturbance regimes and environmental stability.

- **Global Distribution and Carbon Stocks**

Analyses of global mycorrhizal patterns suggest that ecosystems dominated by ectomycorrhizal vegetation store greater soil carbon than arbuscular dominated systems (Soudzilovskaia et al., 2019). Yet correlation does not imply sole causation. Climate, vegetation type, and soil texture also shape these patterns. Fungi contribute significantly, but they operate within complex ecological networks.

Fungal Contributions to Greenhouse Gases

- **Nitrous Oxide Production**

Although bacteria are traditionally emphasized in denitrification studies, fungi such as *Fusarium oxysporum* can produce nitrous oxide under oxygen limited conditions. In fertilized agricultural soils, fungal denitrification may represent a nontrivial fraction of N_2O emissions (Jansson & Hofmockel, 2020). Given the high global warming potential of N_2O, even modest fungal contributions warrant consideration.

- **Methane Dynamics in Thawing Soils**

Fungi do not generate methane directly, yet they shape methane flux indirectly. During permafrost thaw, species such as *Mortierella* decompose ancient organic substrates, supplying carbon to methanogenic archaea (Thurner et al., 2024). In this sense, fungi function as upstream facilitators of methane releases their role is subtle but climatically meaningful.

Pathogens and Vegetation Feedback

Fungal pathogens also influence carbon balance by altering vegetation structure. The historic spread of *Cryphonectria parasitica* eliminated American chestnut populations, reducing biomass and carbon storage. Contemporary warming may enable similar outbreaks in other forest systems. Here, fungi shift from decomposers or symbionts to agents of ecosystem transformation.

Implications for Climate Modeling

Modern Earth system models increasingly incorporate microbial dynamics (Jansson & Hofmockel, 2020). Fungal diversity is often simplified into broad functional categories this reduction risks overlooking trait-based differences in enzyme production, nutrient competition, and temperature response. Greater integration of fungal functional ecology into predictive models will likely improve estimates of soil carbon feedback under future warming scenarios.

Conclusion

Fungi occupy a pivotal yet frequently underestimated position in climate regulation. They do not merely recycle carbon; they govern its persistence, transformation, and atmospheric return. Their ecological roles vary across environments, sometimes enhancing carbon storage and at other times accelerating release. Recognizing this duality is essential climate projections that neglect fungal functional diversity risk oversimplifying soil carbon dynamics. As evidence accumulates, it becomes increasingly clear that understanding the future of Earth’s climate requires understanding the ecology of its fungi.

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Carbon Pools in Mangrove Ecosystems

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Abstract

This chapter provides a comprehensive overview of carbon pools within mangrove ecosystems, distinguishing between aboveground and belowground components. It details the composition of aboveground biomass (AGB), including stems, branches, foliage and highlights the substantial yet often underestimated contribution of belowground biomass (BGB), primarily extensive root systems. A particular focus is placed on soil organic carbon, which constitutes the largest and most stable carbon reservoir in these environments. The chapter synthesises current research on global mangrove carbon stocks, sequestration mechanisms and factors influencing carbon storage, including climate zones, salinity and biodiversity. By consolidating these insights, it underscores the critical importance of mangrove conservation and restoration for carbon cycling and climate resilience.

Introduction

Mangrove forests are unique intertidal ecosystems in tropical and subtropical coasts and key components of the global carbon cycle. Although covering only about 0.36% of global forests, they sequester disproportionately high carbon, earning recognition as “blue carbon” ecosystems [1]. Their high productivity, tolerance to saline and anoxic conditions, and capacity to accumulate organic matter in sediments contribute to long-term carbon storage [2].Beyond carbon sequestration, mangroves provide vital ecosystem services such as coastal protection, biodiversity support, and fisheries enhancement [3]. They also reduce erosion and buffer storm impacts. However, mangroves are among the most threatened ecosystems due to deforestation, aquaculture expansion, coastal development, and climate change–driven sea-level rise [4]. These pressures reduce carbon stocks and ecosystem resilience. Therefore, accurate assessment of carbon pools and understanding sequestration processes are essential for conservation planning. Protecting mangroves strengthens climate change mitigation potential while preserving biodiversity and sustaining coastal livelihoods [1–4].

Carbon Pools in Mangrove Ecosystems

Carbon in mangrove ecosystems is stored in various forms, collectively known as carbon pools. These pools are generally divided into aboveground and belowground components, each contributing uniquely to the overall carbon stock of the ecosystem. The distribution and magnitude of carbon within these pools is influenced by a complex interplay of environmental factors, including species composition, climate, tidal regimes and geomorphology.

Aboveground Biomass (ABG)

Aboveground biomass refers to the living organic matter found above the soil surface. In mangrove trees, AGB primarily includes the stems, branches and foliage. While visually prominent, AGB represents a significant but often smaller fraction of the total ecosystem carbon compared to belowground pools [5]. The carbon stored in AGB is a direct result of photosynthetic activity, where atmospheric carbon dioxide is converted into organic compounds that form the plant's structure. The density and composition of AGB vary considerably among different mangrove species and across different geographical locations, influenced by factors such as tree age, stand density and environmental conditions [6].

Belowground Biomass (BGB)

Belowground biomass (BGB) includes living organic matter beneath the soil surface, mainly mangrove root systems that contribute to nutrient uptake, structural stability, and carbon storage. BGB forms a substantial proportion of total living biomass carbon, and its contribution is often underestimated when only aboveground components are assessed [8]. Mangrove roots are adapted to anoxic and saline environments, with structures such as prop roots and pneumatophores enabling gas exchange and stability in waterlogged sediments. These extensive root networks trap and stabilize sediments, promoting accumulation of organic matter and reducing erosion [9]. By enhancing sediment retention, they indirectly support long-term carbon sequestration. Carbon stored in BGB is less vulnerable to atmospheric release than aboveground biomass because it is protected within the soil matrix and exposed to anaerobic conditions that slow microbial decomposition, thereby strengthening the role of mangroves as durable carbon sinks.

Soil Organic Carbon (SOC)

The primary strength of mangrove carbon sinks lies in soil organic carbon (SOC), which stores 70–98% of total ecosystem carbon depending on site conditions [10][11]. Waterlogged, anaerobic sediments inhibit microbial decomposition, significantly slowing organic matter breakdown and enabling long-term carbon preservation [12]. Additionally, dense mangrove root systems trap and stabilize both allochthonous inputs (tidal sediments) and autochthonous materials such as leaf litter and root exudates. Continuous organic inputs combined with slow decomposition lead to gradual accumulation of thick, carbon-rich sediment layers over centuries to millennia [13]. Global assessments emphasize the major contribution of mangrove SOC to ecosystem carbon budgets. These extensive and stable belowground reserves highlight mangroves as highly effective long-term carbon sinks and underscore their critical role in climate change mitigation and global carbon regulation.

Dead Organic Matter (DOM)

Dead organic matter (DOM) in mangrove ecosystems includes fallen leaves, branches, dead roots and other decaying plant material. While often considered a transient carbon pool, DOM contributes to the overall carbon cycle by gradually breaking down and contributing to the SOC pool. The rate of decomposition of DOM is influenced by factors such as temperature, moisture and the activity of decomposers. In the anaerobic conditions of mangrove soils, the decomposition of DOM is significantly slowed, allowing for greater accumulation and eventual incorporation into the stable SOC pool [15].

Factors Influencing Carbon Storage

The amount of carbon stored in the mangrove ecosystem is not uniform and is influenced by a variety of environmental and biological factors:

- **Climate & Location:** Tropical wet zones maintain the highest carbon densities, while subtropical mangroves show significant growth in accumulation capacity over time. [1].
- **Salinity:** Sediment salinity can indirectly influence carbon storage by affecting the functional composition of mangrove tree accumulations, particularly traits such a wood density and maximum canopy height, which in turn impact aboveground and belowground biomass carbon [10].
- **Environmental Conditions:** Salinity levels influence tree traits like wood density and canopy height, indirectly affecting biomass. Tidal inundation is crucial, creating anoxic (oxygen-poor) conditions that slow decomposition and preserve soil carbon[12].
- **Biodiversity:** Areas with high species and functional diversity—specifically varying wood densities and leaf traits—store more carbon. Protecting diverse, site-specific species is essential for maximizing these ecosystems as natural climate change mitigation tools [10].

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Evaluation of Frameworks for Waste Management in Support of Circular Economy Models

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Abstract

Significant environmental, economic, and social issues are brought about by the world's garbage generation's explosive development. The extraction, production, consumption, and disposal components of traditional linear economic systems have proven unsustainable. By encouraging resource efficiency, waste avoidance, and material recovery, the circular economy model presents a revolutionary alternative. The 3R framework, Extended Producer Responsibility (EPR), Zero Waste, and Integrated Solid Waste Management (ISWM) are among the main waste management frameworks that are assessed in this article for their conformity to the circular economy. The paper evaluates their advantages, disadvantages, and implementation difficulties. While EPR and Zero Waste show a strong connection with circular principles, a comparative analysis shows that an efficient transition to circular systems requires hybrid approaches that integrate economic, technological, and regulatory initiatives.

Keywords: Circular Economy, Waste Management, Zero Waste, Sustainability.

Introduction

The dramatic increase in trash output worldwide is one of the most significant environmental problems of the modern period. Municipal and industrial waste generation has increased due to urbanization, industrial growth, and shifting consumer habits. The linear economic model that underpins traditional waste management systems—often referred to as "take, make, dispose"—causes excessive resource depletion and environmental deterioration. In responce, the circular economy (CE) has become a competitive alternative. In The Ellen MacArthur Foundation actively promotes the idea, which places a heavy emphasis on regenerating natural systems, keeping products and materials in use, and designing out waste. Frameworks for waste management are essential for putting these ideas into practice. This study assesses the main frameworks for waste management and looks at how well they support the concepts of the economy of circles.

The Conceptual Relationship between Waste Management and the Circular Economy.

Traditionally, waste management has focused on the collection, transportation, treatment, and disposal of garbage. However, garbage is reinterpreted as a useful resource in a circular economy perspective. Prevention and material recovery take precedence over disposal. The waste hierarchy offers a methodical way to prioritize waste management techniques: prevention, reduction, reuse, recycling, recovery, and disposal. While landfill disposal is an example of system inefficiency, higher-order techniques like prevention and reuse are highly compatible with circular principles. In order to make the shift to circularity, efficient waste management systems must be integrated with sustainable production, responsible consumption, and product design.

Hierarchy of Waste Management Actions are arranged in a hierarchy based on environmental: 3R, Disposal, and Prevention. The majority of contemporary waste management regulations around the world are based on this hierarchy.

Principal Frameworks for Waste Management

1. Reduce, Reuse, and Recycle

One of the most popular methods for managing garbage is the 3R framework. It encourages reusing materials, prolonging product life cycles, and reducing waste output. Through stringent recycling laws and public awareness efforts, nations like Japan have institutionalized 3R programs.

Advantages

- Easy-to-use and straightforward structure
- Promotes public involvement
- Low cost of implementation Restrictions

Challenges

- Recycling is frequently prioritized above reduction.

Assessment: The 3R framework support the circular economy,s objectives, but it is still limited until it is paired with financial and regulatory incentives.

2. Extended Accountability for Producers

EA producers were responsible for post-consumer management. Manufacturers are responsible for the long-term effects of their products on the environment.Under its Waste FrameworkDirective, the European Union has put EPR into effect, especially for packaging and electronic waste.

Advantages
- Promoting eco-design
- Internalizes environmental expenses
- Encourages infrastructure for recycling

Challenges
- The difficulties of monitoring and enforcement

Assessment: Because EPR targets waste generation at the production stage, it is highly consistent with the concepts of the circular economy.

3. Framework for Waste- Free

By preventing trash and redesigning systems, the Zero trash strategy aims to do away with landfills and incineration. Cities with significant diversion rates, like San Francisco, have enacted aggressive zero-waste rules.

Advantages
- A strong focus on prevention
- Encourages a shift in conduct
- Promotes the designing of sustainable products Restrictions

Challenges
- A large investment in infrastructure Strong governance is necessary.

Assessment: Although Zero Waste has a high degree of agreement with circular ideas, it necessitates sustained dedication and public involvement.

4. Integrated Solid Waste Management (ISWM)

ISWM incorporates waste management's technical, economic, environmental, and social aspects. It covers energy recovery, composting, recycling, garbage collection, segregation, and safe disposal. ISWM has been used in nations like India to handle the escalating problems associated with municipal garbage.

Advantages
- Adaptable and expandable
- Includes the unorganized sector
- A comprehensive operating strategy Restrictions

Challenges
- Treatment was prioritized above prevention

Assessment: Although ISWM offers useful operational efficiency, for maximum impact, circular production rules must be incorporated.

Support for Circular Waste Systems in Policy

The European Commission introduced the circular Economy Action Plan to enhance recycling targets and sustainable product regulations across Europe. Similarly, Chaina enacted the circular Economy Promotion Law, which placesan emphasis on industrial symbiosis and resource efficiency. Legislative frameworks significantly improve the efficiency of waste management in achieving circular outcome.

Important Performance Measures Measurable Markers Like These Are Necessary for an Effective Evaluation.

The amount of garbage generated per person. The rate of recycling:

- The rate of landfill diversion
- Rate of use of circular materials
- Reduction of greenhouse gas emissions
- Productivity of resources Performance evaluation is strengthened by sophisticated analytical instruments such as Life Cycle Assessment (LCA) and Material Flow Analysis (MFA).

Implementation Obstacles Among the Main Obstacles Are

- Inadequate methods of enforcement
- Unstable markets for recycled goods

Emerging Innovations

New Developments Models of industrial symbiosis, like those in Kalundborg, show how efficient by-product exchange systems can lower utilizing unprocessed materials.

Digital technology like blockchain monitoring and AI-based garbage sorting increase operational efficiency and Transparency.

Conclusion

Frameworks for waste management are crucial tools for the shift to circular economy systems. Modern frameworks increasingly encourage prevention, producer responsibility, and systemic change, whereas traditional systems prioritize disposal. Sustainable resource management requires a hybrid strategy that combines EPR, Zero Waste concepts, functional ISWM technologies, and robust policy backing. An important change in economic and environmental governance is represented by the shift from waste management to resource management.

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The Proliferation of Water Lettuce in River Systems: Causes, Consequences, and Control

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Abstract

Due to nutrient enrichment, hydrological change, and climate change, water lettuce (Pistia stratiotes L.), a highly invasive floating macrophyte. It has spread throughout numerous river systems worldwide. Dense mats cause major economic and social costs, alter ecosystem structure, interfere with hydrology, and degrade water quality. In addition to assessing developments in mechanical, chemical, biological, and basin-scale management techniques, this chapter summarizes current knowledge of the species' biology, invasion dynamics, environmental causes, and ecological consequences. Combining coordinated, multi-method intervention with catchment-level nutrient reduction is necessary for effective long-term control.

Keywords: Hydrology, Pistia, invasion, water quality, ecological consequences.

Introduction

River ecosystems are dynamic freshwater environments that sustain human lifestyles, provide water supplies, control nutrient flows, and promote biodiversity. However, invasive aquatic plants that profit from nutrient loading, hydrological modification, and climate-driven warming are affectation a growing threat to them (Simberloff et al., 2013). Ecosystem functioning is significantly altered by dense mats of free-floating macrophytes (European and Mediterranean Plant Protection Organization [EPPO], 2020). Water lettuce (Pistia stratiotes), is a macrophyte that floats freely and creates large surface mats (EPPO, 2020; CABI, 2013). It has now spread throughout tropical and subtropical areas, despite the fact that its biogeographic origin is still remains debated (CABI, 2013; U.S. Fish and Wildlife Service, 2025). Through vegetative reproduction and fragmentation, Pistia spreads quickly in rivers, allowing small propagules to colonize downstream habitats (EPPO, 2020; CABI, 2013).

Water quality and habitat structure are transformed by nutrient enrichment from sewage, industrial effluents, and agricultural runoff, which speed up development of water lettuce and promotes thick biomass (Lu et al., 2010; EPPO, 2020; U.S. Fish and Wildlife Service, 2025). Light limitation, decreased dissolved oxygen, suppression of native producers, and interference with navigation and other water uses are among the ecological, hydrological, and socioeconomic consequences (EPPO, 2020; CABI, 2013; U.S. Fish and Wildlife Service, 2025). The dynamics of Pistia stratiotes invasion in rivers are thoroughly examined in this chapter. In order to assist integrated, evidence-based management, it summarizes the most recent information on its ecological characteristics, spread routes, effects, and control strategies.

Biology and Invasion Ecology

Buoyant rosettes and long, fibrous roots that improve nutrient uptake from the water column and suspended particles are characteristics of water lettuce (EPPO, 2020; CABI, 2013). It contributes to a durable seed bank and the possibility of long-distance dispersal by vegetative reproduction through stolons and sexual reproduction through seed production (CABI, 2013). Rapid mat development and competitive suppression of native species are made possible by high growth rates in warm, nutrient-rich environments (EPPO, 2020). The ability of populations to overwinter in mild or thermally modified climates allows them to spread beyond conventional climatic boundaries (Šajna et al., 2007; MacIsaac et al., 2016; U.S. Fish and Wildlife Service, 2025). Invasion success is further enhanced by the species' phenotypic plasticity and numerous human-mediated introduction channels (CABI, 2013; U.S. Fish and Wildlife Service, 2025).

Causes of Proliferation in River Systems

- **Nutrient Enrichment and Eutrophication**

Nutrient enrichment from agricultural runoff, wastewater discharge, and urban stormwater promotes eutrophic conditions that favour P. stratiotes proliferation (Lu et al., 2010; EPPO, 2020; U.S. Fish and Wildlife Service, 2025). The species is highly efficient at nutrient uptake and has been successfully used in controlled systems to remove nitrogen and phosphorus from eutrophic stormwaters (Lu et al., 2010). In open rivers, continual nutrient inputs can reinforce mat persistence through positive feedbacks, as expanding mats intercept more suspended nutrients and organic matter (EPPO, 2020; CABI, 2013).

- **Hydrological Alteration and Habitat Modification**

Flow regulation through dams, weirs, and channel simplification creates low velocity habitats ideal for P. stratiotes establishment (EPPO, 2020; CABI, 2013).

Hydraulic structures can trap floating biomass, increase hydraulic resistance, and promote upstream water level rise (EPPO, 2020). High flow events may fragment mats and disperse propagules downstream, turning rivers and canals into invasion corridors (EPPO, 2020; CABI, 2013).

- **Climate Change and Range Expansion**

Increasing temperatures, fewer frost events, and longer growing seasons are expected to enhance P. stratiotes growth, reproduction, and overwinter survival in temperate regions (MacIsaac et al., 2016; U.S. Fish and Wildlife Service, 2025). Under warming scenarios, suitable climatic space for the species expands, while extreme rainfall can increase nutrient and sediment loads and indirectly promote macrophyte proliferation (U.S. Fish and Wildlife Service, 2025). Without nutrient reduction and strengthened prevention measures, intermittent outbreaks may become persistent (EPPO, 2020; U.S. Fish and Wildlife Service, 2025).

Ecological, Economic, and Social Consequences

- **Ecosystem Structure and Function**

Dense mats of P. stratiotes reduce light penetration, suppress submerged macrophytes and phytoplankton, and shift primary producer communities (EPPO, 2020; CABI, 2013). Reduced gas exchange at the air–water interface and elevated decomposition rates can promote hypoxic or anoxic conditions that impair benthic fauna and alter nutrient cycling (EPPO, 2020). Root systems trap fine sediments, changing substrate characteristics and favouring tolerant invertebrates over more sensitive taxa (EPPO, 2020).

- **Hydrological and Infrastructural Impacts**

Large mats obstruct navigation, reduce flow conveyance, and accumulate against hydraulic structures, thereby increasing flood risk (EPPO, 2020; CABI, 2013). In irrigation canals and hydropower facilities, water lettuce clogs intakes and reduces operational efficiency (EPPO, 2020). Management costs for floating invasive macrophytes, including P. stratiotes, can be substantial in heavily infested regions (U.S. Fish and Wildlife Service, 2025).

- **Human Health and Livelihoods**

Water lettuce mats impede small boat movement, limit access for fishing, and reduce recreational value of waterways (CABI, 2013). Stagnant waters beneath dense mats provide habitat for mosquitoes and other disease vectors, contributing to public health concerns (EPPO, 2020). Rural communities relying on rivers for irrigation and domestic water can face increased labour and pumping costs when infestations are severe (CABI, 2013).

Control and Management Strategies

- **Mechanical and Physical Control**

Mechanical harvesting using barges, aquatic weed harvesters, and manual removal is widely used to clear channels and protect infrastructure (EPPO, 2020; CABI, 2013). Floating booms and barriers can intercept mats and reduce downstream spread (EPPO, 2020). However, mechanical methods often provide only temporary relief when nutrient levels remain high (EPPO, 2020).

- **Chemical Control**

Herbicides such as glyphosate and diquat have been used to control P. stratiotes where mechanical removal is impractical (EPPO, 2020; U.S. Fish and Wildlife Service, 2025). While effective in reducing biomass, concerns over non-target impacts and water quality degradation following plant die off have led to more regulated and targeted applications (EPPO, 2020). Chemical treatments are generally recommended only as part of integrated management programmes (EPPO, 2020; U.S. Fish and Wildlife Service, 2025).

- **Biological Control**

Biological control using host-specific weevils, especially Neohydronomus affinis, has provided long term suppression of water lettuce in several regions (CABI, 2013; Center for Invasive Species Management, 1994). These agents can be cost effective and self-sustaining but typically require multiple seasons to achieve substantial biomass reduction and are sensitive to environmental conditions (CABI, 2013).

- **Nutrient and Pollution Management**

Reducing nutrient inputs through improved wastewater treatment, agricultural best management practices, and stricter effluent regulation is essential for long term control (Lu et al., 2010; EPPO, 2020). Constructed wetlands and treatment ponds can intercept pollutants before they reach rivers, but they require careful design and management to prevent escape and subsequent invasion by P. stratiotes (Lu et al., 2010; U.S. Fish and Wildlife Service, 2025).

- **Integrated Basin-Scale Management and Policy**

Integrated basin scale strategies are increasingly recognized as critical for effective long-term management of floating invasive macrophytes (EPPO, 2020; U.S. Fish and Wildlife Service, 2025). These approaches emphasize coordinated control among upstream and downstream stakeholders, early detection and rapid response, public education, and robust regulatory frameworks (U.S. Fish and Wildlife Service, 2025). Aligning P. stratiotes management with broader water quality improvement and climate adaptation policies enhances overall effectiveness (EPPO, 2020; U.S. Fish and Wildlife Service, 2025).

Conclusion

The invasion of Pistia stratiotes in river systems represents a significant ecological and management challenge. Its rapid growth, capacity to alter hydrological conditions, and impacts on biodiversity highlight the urgent need for integrated monitoring and control strategies. Effective management requires combining mechanical, biological, and ecological approaches while addressing nutrient enrichment and other anthropogenic drivers. Strengthening research, policy coordination, and community engagement will be essential for preventing further spread and safeguarding riverine ecosystem health.

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Sustainable Agriculture in the Era of Climate Change: Resilient Farming Systems

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Abstract

Climate alteration is a key challenge for global agriculture system, affecting food security, crop yield and farmer source of revenue through increasing temperatures, irregular rainfall and frequent extreme weather events. These changes increase abiotic stresses like salinity, drought, heat and flooding, while also intensifying biotic stresses caused by insect, pest, pathogens and diseases. Additionally, climate-induced biodiversity declines interrupt fundamental ecosystem processes such as pollination, nutrient recycling and biocontrol, further weakening agricultural resilience. Sustainable and climate-smart agricultural activities such as natural farming, sustainable agriculture and agroforestry play an important function in enhance soil health, protecting resources and supporting resilient farming systems. Advances in plant breeding and biotechnology are enabling the advance of climate resilient crop variability, while adaptation strategies like efficient water management, crop diversification and improved seed systems help farmers manage climatic risks. Emerging digital technologies, including artificial intelligence, remote sensing and mobile advisory services, are also enhancing farm decision-making. However, effective policy support, research investment and international cooperation are essential to ensure these innovations reach vulnerable farming communities. This chapter examines the effect of climate change on agriculture and highlights sustainable strategies, technological innovations and policy approaches needed to build resilient agricultural systems.

Keywords: Climate alteration, Sustainable agriculture, Climate-smart agriculture, Crop resilience, Food security.

Introduction

Farming system is backbone of food security, rural economies, and ecosystem stability. However, ongoing climatic changes are reshaping agricultural landscapes worldwide. Rising effect of greenhouse gas emissions from fossil fuel burning, deforestation, industrialization and transportation have accelerated global warming, leading to unpredictable weather patterns and extreme climatic events (Intergovernmental Panel on Climate Change, 2023). Climate change imposes multiple abiotic stresses, including drought, salinity, flooding, extreme heat and cold, heavy metal toxicity, and oxidative stress (Mittler, 2006). Simultaneously, biotic stresses caused by fungi, bacteria, viruses, insects, and other pathogens are intensifying (Savary et al., 2019). These stressors disrupt plant physiological processes, reduce growth and development, and ultimately lower crop yield and quality (Hasanuzzaman et al., 2013). Consequently, food security, farmer livelihoods, and ecosystem services are increasingly at risk (IPCC, 2023). Effective crop stress management and resilient farming systems have therefore become essential components of sustainable development.

Climate Change and Its effect on Agriculture

• Rising Temperatures

Rising global temperatures are the greatest consequence of climate change. Elevated temperatures increase transpiration rates reduce photosynthetic efficiency because heat stress and photo-inhibition lead to leaf scorching and reproductive failure (Wahid et al., 2007). These physiological disruptions impair biomass accumulation and reduce final yield. Prolonged exposure to high temperatures during flowering and grain filling stages can severely affect crop productivity, thereby threatening global food security (Lobell & Gourdji, 2012).

• Erratic Rainfall and Extreme Weather Events

Unpredictable rainfall patterns, prolonged droughts, floods, storms, hailstorms, and heat waves have become more frequent and intense (Food and Agriculture Organization, 2017). Such extreme events damage crops during critical growth stages reduce grain and fruit quality because soil erosion and nutrient leaching affect livestock health disrupt agricultural operations (Lal, 2015). Heavy rainfall during harvesting seasons, for instance, leads to post-harvest damages and economic instability of farmers. Overall, these events increase production risks and reduce farm profitability (FAO, 2017).

• Biodiversity Loss

Climate change significantly affects biodiversity by altering temperature and precipitation regimes (Bellard et al., 2012). These changes disturb species distribution, disrupt ecological interactions, and lead to habitat degradation.

Biodiversity loss weakens essential ecosystem services such as pollination, nutrient cycling and natural pest regulation (Cardinale et al., 2012). The decline of beneficial organisms ultimately reduces agricultural resilience and sustainability.

Climate-Smart Agricultural Practices

Climate-smart agriculture integrates adaptation and mitigation strategies while maintaining productivity (FAO, 2013). Several approaches contribute to resilient farming systems.

- **Organic Agriculture**

Organic farming is a holistic production scheme that conserve soil nature, ecosystem balance, and human well-being. It depends on natural processes and biological diversity, natural process rather than synthetic fertilizers and pesticides (Reganold & Wachter, 2016). According to International Federation of Organic Agriculture Movements (IFOAM – Organics International), organic agriculture is guided by four fundamental principles: Health, Ecology, Fairness, Care (IFOAM, 2015). Sustainable agriculture practices like composting, crop alteration, green manuring, biocontrol and bio-pesticide application enhance soil fertility and reduce environmental pollution. These approaches strengthen resilience against climatic stress while promoting sustainable vegetable and crop production (Reganold & Wachter, 2016).

- **Conservation Agriculture**

Conservation agriculture emphasizes minimum soil disturbance Permanent soil cover Crop rotation and diversification (Hobbs et al., 2008). These processes enhance soil nature, water retention, carbon sequestration and reduce erosion. They also contribute to long-term productivity under changing climatic conditions.

- **Agroforestry**

Agroforestry combines growing trees, crops and animals. It improves biodiversity, microclimatic conditions, prevents soil erosion, and increases carbon storage (World Agroforestry, 2018). Trees act as windbreaks and provide shade, thereby reducing temperature stress on crops.

Biotechnology in Climate-Resilient Agriculture

Progresses in plant genetics and biotechnology offer promising tools to develop climate-resilient crops. Genetic improvement enables the development of varieties with heat and drought tolerance, salinity resistance, disease and pest resistance, improved nutrient-use efficiency (Varshney et al., 2021), introducing genes that confer stress resistance enhances crop stability and economic yield. Promoting locally adapted and stress-tolerant varieties further strengthens resilience against both biotic and abiotic challenges. Biotechnology, when integrated responsibly with ecological farming principles, can significantly support sustainable agricultural transformation.

Adaptation and Mitigation Strategies

- **Adaptation Strategies**

Adaptation focuses on adjusting farming practices to reduce vulnerability. The key strategies include efficient irrigation and water harvesting systems, crop diversification, integrated nutrient management, improved seed systems, Climate-resilient cropping calendars (FAO, 2013).

- **Mitigation Strategies**

Mitigation aims to reduce greenhouse gas emissions from agriculture through precision fertilizer application, improved manure management, renewable energy use on farms, soil carbon sequestration, reduced tillage practices (IPCC, 2023), combining adaptation and mitigation ensures both resilience and environmental sustainability.

Digitalization in Agriculture

Digital knowledges are altering modern agronomy. Tools like artificial intelligence, large information analytics, mobile advisory platforms, remote sensing, and blockchain enhance decision-making and supply chain transparency (Wolfert et al., 2017). Early warning systems and climate forecasting tools help farmers prepare for extreme weather events. Mobile-based agricultural extension services are especially beneficial in rural areas with limited infrastructure, improving access to real-time information and market linkages. Digital agriculture strengthens risk management and improves overall farm efficiency.

Socioeconomic Implications

Climate change impacts extend beyond crop production. Smallholder farmers, particularly in developing countries, are disproportionately vulnerable due to limited financial and technological resources (Morton, 2007). Reduced productivity leads to income instability, increased poverty, migration, social vulnerability, agriculture-dependent economies face macroeconomic risks when climate shocks reduce national output. Therefore, equitable development strategies are essential to protect vulnerable communities.

Climate-Smart Policies and Global Agreements

International frameworks such as the Paris Agreement emphasize both adaptation and mitigation in agricultural systems (IPCC, 2023). Many countries incorporate agricultural emission reduction and resilience targets within their Nationally Determined Contributions (NDCs). Effective public policies should promote the subsidies for sustainable inputs, Carbon credit mechanisms, and crop insurance reforms, Investment in agricultural research and development. Strengthened climate information services, Policy support, scientific research, farmer education and international collaboration are critical for long-term sustainability.

Conclusion

Environment change possesses thoughtful challenges to global agriculture by altering temperature patterns, rainfall distribution and Magnitude of pest and disease occurrence. These changes threaten Plant production efficiency, particularly Smallholder agricultural producers. At the same time, the situation offers an opportunity to transform agricultural systems toward greater resilience and sustainability. The implementation of Climate-smart approaches, including organic farming, conservation agriculture, and agroforestry, contribute to healthier soils, responsible resource use, and more stable ecosystems. Progress in biotechnology, better water management, crop diversification, and resilient seed systems play an important role in helping farmers adapt to changing climatic conditions. In addition, digital technologies that provide climate information and decision-support tools can enhance farm management and productivity. However, technological solutions alone are not sufficient. Effective policies, farmer education, financial support and strong institutional and international cooperation are essential to ensure that innovations reach vulnerable farming communities. Coordinated efforts at global, national and local levels are therefore necessary. Ultimately, building climate-resilient agricultural systems is crucial for sustaining food production, protecting rural livelihoods, and preserving environmental health. Sustainable agriculture is not just a choice it is essential for ensuring long-term food security and protecting the planet.

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Climate Change and Green Technologies

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Abstract

Climate change is a major global challenge caused largely by greenhouse gas emissions from deforestation, industrialization, and fossil fuel use. Its impacts include rising temperatures, melting glaciers, sea level rise, and extreme weather, creating serious social and economic risks, especially for vulnerable communities. Green technologies play a crucial role in mitigating these effects by reducing carbon emissions and promoting sustainable development. Key solutions include renewable energy sources like solar and wind, energy-efficient systems, green buildings, and sustainable transportation. Additional approaches such as carbon capture and circular economy practices further support environmental protection. Despite challenges in developing countries, investment and policy support are essential to promote adoption.

Introduction

The world faces major environmental challenges such as climate change, global warming, pollution, deforestation, and resource depletion. Rapid industrialization, population growth, and dependence on fossil fuels have disturbed ecological balance, creating an urgent need for sustainable solutions. Green technology offers an effective approach by promoting environmentally friendly practices that reduce pollution, conserve energy, and ensure efficient use of natural resources. It includes renewable energy sources like solar and wind, energy-efficient systems, waste management, water conservation, and sustainable agriculture. The primary aim of green technology is to achieve sustainable development by balancing economic growth with environmental protection. It not only reduces carbon emissions and conserves resources but also improves public health and generates employment opportunities, ensuring a cleaner and more sustainable future.

Understanding Climate Change

- **The Science of Climate Change**

Energy transfers between the sun, the earth's surface, and the atmosphere control climate systems. Heat is trapped in the atmosphere by greenhouse gases (GHGs), which include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The globe warms as a result of the greenhouse effect being exacerbated by the rise in these gases.

Some of the main causes of rising GHGs are:

  - Burning fossil fuels for transportation and energy production
  - Processes in industry
  - Agriculture (rice paddies, livestock methane)
  - Changes in land usage, particularly in deforestation

- **Impacts on Ecosystems and Societies**

Human systems and ecosystems around the world are impacted by climate change such as:

  - Changes in weather patterns and heatwaves are caused by rising temperatures.
  - Sea level rise is a result of glaciers and ice sheets melting.
  - Marine ecosystems are harmed by ocean warming and acidity.
  - Droughts and floods are exacerbated by shifting rainfall patterns.
  - Health hazards, displacement, and decreased agricultural production are examples of socioeconomic effects.

The Role of Green Technologies

Green technologies play a vital role in environmental protection and sustainable development by reducing pollution, conserving resources, and addressing climate change. They promote renewable energy sources like solar, wind, and hydropower, lowering carbon emissions and fossil fuel dependence. These technologies also enhance water conservation, waste management, sustainable agriculture, and energy efficiency in buildings. Overall, they support economic growth, generate employment, and ensure a cleaner, healthier, and more sustainable future.

Sustainable Energy Options

The key to mitigating climate change is switching from fossil fuels to renewable energy sources.

- **Sunlight Power**

The Sun provides sunlight power, often known as solar energy, which is a renewable energy source. Solar panels use photovoltaic cells to convert sunlight into electrical power. Homes, schools, and businesses can all use this electricity. Environmentally friendly, solar energy is limitless, pure, and pollution-free. It is dependent on sunshine, though, and might not generate power at night or on overcast days.

- **Wind-Powered Energy**

Wind power is a renewable energy source that uses the force of moving air to generate electricity. Wind turns turbine blades, which drive a generator to produce power for homes, businesses, and institutions. It is clean and environmentally friendly, producing no pollutants and reducing reliance on fossil fuels. However, wind energy depends on wind availability and requires high initial investment. Many countries, including the US, China, and India, use wind energy for sustainable electricity generation.

- **Geothermal and Hydropower**

Geothermal energy is a renewable source derived from the Earth's internal heat, where steam is used to drive turbines and generate electricity. It is reliable and available year-round but limited to geothermal regions. Hydropower generates electricity using flowing or falling water that spins turbines. It is a widely used and efficient renewable source, though dam construction can be expensive and may impact ecosystems.

1. Smart Systems and Energy Efficiency

Overall emissions are decreased by lowering the energy needed to supply goods and services.

Energy-efficient structures with sophisticated climate management, LED lighting, and better insulation. Industrial energy management for process optimization. Smart networks that incorporate dispersed renewable energy sources and manage supply and demand

2. Hygienic Transportation

A large portion of emissions comes from transportation. Mobility is changing due to green technologies:

- Advances in battery technology increase battery longevity and range, while electric vehicles (EVs) lower exhaust emissions.
- For large transportation, hydrogen fuel cells provide emission-free options.
- Reliance on private automobiles is lessened by public transportation and active mobility (walking, bicycling).

3. Capturing and Utilizing Carbon (CCU)

By using these technologies, CO_2 is eliminated from emissions streams or the atmosphere:

- The process of carbon capture and storage (CCS) captures and stores CO_2 from industrial sources underground.
- CO2 is extracted from ambient air via direct air capture (DAC).
- Carbon utilization transforms captured CO2 into goods that may be used, such as construction materials, fuels, or chemicals.

4. Sustainable Land Use and Agriculture

Climate-smart agriculture is further supported by green technologies:

- Sensors and data analytics are used in precision farming to maximize inputs and raise yields.
- Regenerative techniques like agroforestry improve soil carbon storage.
- Crop resilience to climate stress is enhanced by biotechnology.

Economics, Policy, and Innovation

1. Frameworks for Enabling Policies

- National decarbonization and climate action plans
- Support for green technology R&D
- Green public procurement policies
- Energy efficiency standards and building codes
- Carbon emission reporting and monitoring
- Urban sustainability and local climate strategies
- Strong environmental regulations and enforcement
- Green job training and skill development programs.

2. Investment and Funding

- Green banking and sustainable finance
- Green finance support for SMEs
- Carbon markets and emissions trading
- Climate risk assessment and insurance
- Promotion of eco-friendly businesses
- FDI in clean technologies
- Government investment in sustainable infrastructure
- Promotion of circular economy for resource efficiency.

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Plant Secondary Metabolites and Human Health

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Abstract

Plants produce a diverse range of secondary metabolites—organic compounds not directly involved in growth or reproduction but vital for adaptation. These phytochemicals, numbering in the hundreds of thousands, perform roles as plant defenses, attractants, and signaling molecules. Recent research has highlighted their impact on human health, especially as antioxidants, anti-inflammatory agents, antimicrobials, and potential pharmaceuticals. Alkaloids, phenolics, flavonoids, terpenoids, saponins, and glycosides are widely studied for disease prevention and therapy, though some may pose toxic risks if overconsumed. This article reviews the classification, biosynthesis, actions, and applications of plant secondary metabolites, emphasizing both benefits and necessary precautions.

Introduction

Plant secondary metabolites have fascinated scientists for centuries. Morphine from *Papaver somniferum* has been used for pain relief since the 19th century, and recent work (Hussain *et al.*, 2023) suggests neuroprotective effects. The challenge is balancing therapeutic potential and toxicity (Wink 2003; Patel, Goyal, and Sharma 2021). Ganesan and Xu (2022) showed that high-flavonoid diets may lower heart disease risk, though effects may vary with genetics and diet, highlighting the need for integrated research across chemistry, biology, and medicine.

Beyond medicine, secondary metabolites such as alkaloids, phenolics, flavonoids, terpenoids, saponins, and glycosides are crucial for plant adaptation (Mann 2012; Wink 2020). They mediate interactions with other organisms and play key roles in traditional medicine and drug discovery (Batiha *et al.*, 2023). Advances in analytical techniques and genomics have clarified their biosynthesis and bioavailability (Crozier, Jaganath, and Clifford 2009; Xu *et al.*, 2023). Yet, translating biochemical data into health advice remains complex due to individual differences in metabolism and microbiota (Liu 2013; Ganesan and Xu 2022).

Classification and Biosynthesis

Secondary metabolites are typically grouped as alkaloids, phenolics (including flavonoids), terpenoids, saponins, and glycosides (Mann 2012; Wink 2020). Each class represents distinct evolutionary solutions to ecological pressures.

Alkaloids are nitrogen-containing compounds with strong physiological effects. Morphine and quinine are classic examples, with ongoing research into antimicrobial and neuroprotective properties (Hussain *et al.*, 2023). Phenolic compounds, from simple acids to tannins, act as antioxidants and signaling molecules (Crozier, Jaganath, and Clifford 2009). Flavonoids, a major phenolic subgroup, are linked to cardiovascular benefits (Ganesan and Xu 2022). Terpenoids serve as pigments and volatile attractants, with genomics revealing hybrid biosynthetic pathways (Xu *et al.*, 2023). Saponins and glycosides interact with membranes and cholesterol metabolism but may cause nutritional issues if overconsumed (Patel, Goyal, and Sharma 2021).

Biosynthetic pathways like the shikimate, mevalonate, and MEP pathways are central to production. Modern metabolic engineering enhances beneficial phytochemicals in crops (Xu *et al.*, 2023).

Mechanisms of Action and Health Effects

Secondary metabolites act via diverse mechanisms, not just as antioxidants. Many modulate cell signaling, including NF-κB and MAPKs (Sharma *et al.*, 2022; Batiha *et al.*, 2023), influencing inflammation and cell death. Alkaloids offer neuroprotection but can be toxic (Hussain *et al.*, 2023). Flavonoids and catechins regulate genes related to inflammation and lipid metabolism (Ganesan and Xu 2022). Saponins can promote cholesterol excretion yet impair vitamin absorption if overused (Patel, Goyal, and Sharma 2021).

Disease Prevention and Toxicity

Epidemiological and lab studies support secondary metabolites in disease prevention, though causality is hard to prove. Polyphenol-rich diets may reduce cardiovascular and depression risks (Grosso *et al.*, 2017), and phytochemicals can inhibit tumor progression. However, bioavailability and possible toxicity at high doses remain barriers (Liu 2013; Ganesan and Xu 2022). Polyphenols may improve glucose metabolism in animals, but human trials are mixed (Hanhineva *et al.*, 2010). Flavonoids and terpenoids may affect neuroinflammation (Wink 2020).

Not all effects are beneficial: tannins and phytic acid can block mineral absorption, while saponins and glycosides may be toxic if not processed properly (Pandey and Rizvi 2009; Patel, Goyal, and Sharma 2021; Sharma *et al.*, 2022). Traditional food processing helps reduce these risks.

Applications and Future Directions

Plant secondary metabolites are used in medicines (e.g., paclitaxel, cardiac glycosides) and functional foods. Metabolic engineering aims to boost beneficial compounds, though ecological impacts must be studied (Tholl 2023; Xu *et al.*, 2023). Future research combining omics and personalized medicine promises clearer dietary guidelines (Li *et al.*, 2022). Careful trials and understanding gene–diet–environment interactions are essential.

In summary, plant secondary metabolites offer health benefits and complexity. Responsible use depends on integrating scientific, clinical, and traditional knowledge.

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First Report on the Antihemolytic and Membrane Stabilizing Potential of *Sonneratia alba* Fruit Extract

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Abstract

This investigation aimed to determine the membrane protective effect of *Sonneratia alba* fruit extract against hemolysis by employing the human red blood cell (HRBC) membrane stabilization method. Erythrocyte lysis was triggered under hypotonic stress, and the extent of protection offered by the extract was quantified by spectrophotometric estimation of released hemoglobine, the tested extract showed a concentration-dependent inhibitory effect on hemolysis, showing an IC50 of 66.08µg/mL, indicating notable stability of the erythrocyte membrane. The observed activity suggests that the fruit extract possesses considerable cytoprotective property. To our knowledge, this work provide the first experimental evidence supporting the antihemolytic potentioal of *S.alba* fruit extract as anatural membrane stabilizing agent.

Keywords: *Sonneratia alba* fruit; Antihemolytic activity; HRBC membrane stabilization; Erythrocytes protection.

Introduction

Sonneratia alba is a mangrove species whose fruit has been utilized in traditional healthcare practices for treating various disorders, suggesting its potential therapeutic significance13. Mangrove plants are recognized as valuable sources of diverse bioactive secondary metabolites12. Although the fruit of *S. alba* is traditionally regarded as medicinally important, systematic pharmacological evaluation of its biological properties remains limited5. Antihemolytic activity refers to the ability of a substance to protect red blood cells from membrane damage and prevent hemoglobin leakage under stress conditions. The HRBC membrane stabilization method is widely used as an in vitro model to evaluate membrane-protective and anti-inflammatory properties due to similarities between erythrocyte and lysosomal membranes. Substance that inhibit hemolysis by stabilizing erythrocyte membranes are therefore considered to have cytoprotective potential7.

Study Area

The fruits were collected from the mangrove forests of Dabhol, located in Ratnagiri district, Maharashtra, India (17°35′14.15″N, 73°10′29.23″E), where *Sonneratia alba* is a dominant mangrove species. Fig1

Fig 1: Study area map

Fruit About

Figure 2. Morphology of *Sonneratia alba* fruit showing its disc-shaped structure and smooth pericarp. *Sonneratia alba* (family Sonneratiaceae), commonly known as mangrove apple, produces a globose to slightly flattened berry measuring approximately 3–6 cm in diameter. The fruit possesses a smooth outer surface that transitions from green at the immature stage to yellowish-brown upon ripening, often with a distinct central depression. It develops directly from the trunk or mature branches and encloses numerous small seeds within a differentiated pericarp comprising exocarp and mesocarp layers. Adapted to saline intertidal mangrove environments, the fruit is locally consumed in certain coastal regions. Studies have indicated the presence of several bioactive compound such as phenolics, flavonoide, tannins, saponin, sterols, and triterpenoids, along with essential minerals, including calcium, magnesium, and potassium13. These constituents are known to contribute to various biological properties like antioxidant, anti-inflammatory, antimicrobial, and membrance-stabilizing activities 10,14,15.

Fig 2: ***Sonneratia alba*** **fruit**

Mechanistic Link Between Antioxidant and Antihemolytic Activity

Several studies have documented significant antioxidant activity in different *Sonneratia species*. Extracts of *S. alba* leaves, bark, stem, root, and fruit have demonstrated moderate to strong DPPH radical scavenging activity depending on solvent type and phytochemical composition (Gawali & Jadhav, 2011; Milon et al., 2012; Asad et al., 2013; Haq et al., 2014; Wijaya et al., 2023; Wonggo et al., 2024). Similarly, *S. caseolaris, S. apetala, and S. ovata* have exhibited potent antioxidant activity in DPPH, ABTS, and related assays, largely attributed to the presence of phenolics, flavonoids, tannins, and triterpenoids (Hossain et al., 2012; Laili et al., 2018; Munira et al., 2019; Audah et al., 2022; Astuti et al., 2023; Cerri et al., 2025). Overall, antioxidant efficacy within the genus is strongly correlated with its rich polyphenolic composition.

The antioxidant activity of *Sonneratia* extracts may protect erythrocyte membranes by scavenging free radicals and inhibiting lipid peroxidation, explaining their antihemolytic effects.

Plant Extraction

Fresh fruits of *Sonneratia alba* were collected from the mangrove area of Dabhol and washed thoroughly. About 10 g of fruit pulp was crushed and mixed with 50 mL DW to prepare extract, which was then stirred, filtered using Whatman NO.1 filter paper, and store at 4ºC for further antihemolytic analysis.

Methodology

Membrane Stabilization (Antihemolytic) Method

Fresh human blood was obtained, and erythrocytes were separated by centrifugation at 3000 rpm for a duration of 10 minutes, followed by repeated washing with isotonic saline. A 10% suspension of erythrocytes was then prepared using in phosphate buffer (pH 7.4). The reaction mixture contained of extract at different concentrations, phosphate buffer, and erythrocyte suspension.

The mixtures were incubated at 37°C for 30 minutes and subsequently centrifuged at 3000 rpm for a duration of 10 minutes. Hemolysis was cause by adding a hypotonic solution (0.36% NaCl). The absorbance of the resulting supernatant was recorded at 540 nm to assess the extent of hemolysis. The percentage of membrane stabilization was calculated in comparison with the control sample 1,9. Figure 3

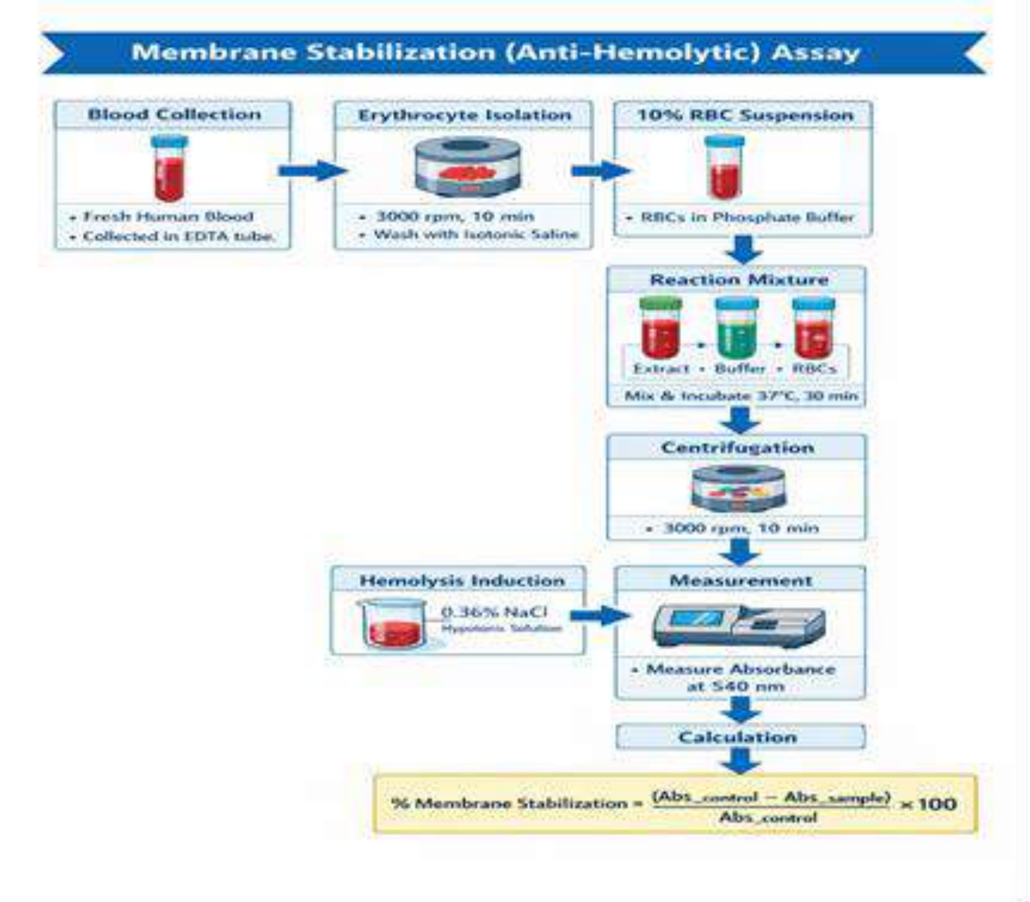

Figure3. HRBC membrane stabilization assay.

Observation

Table 1. Antihemolytic of fruit extract at different concentrations (mean ± SD, n = 3).

Concentration (µg/ml)	**Fruit sample % inhibition of hemolysis**	**Positive control % inhibition of hemolysis**
10	16.39%	45.12%
50	29.36%	68.45%
100	82.71%	94.20%

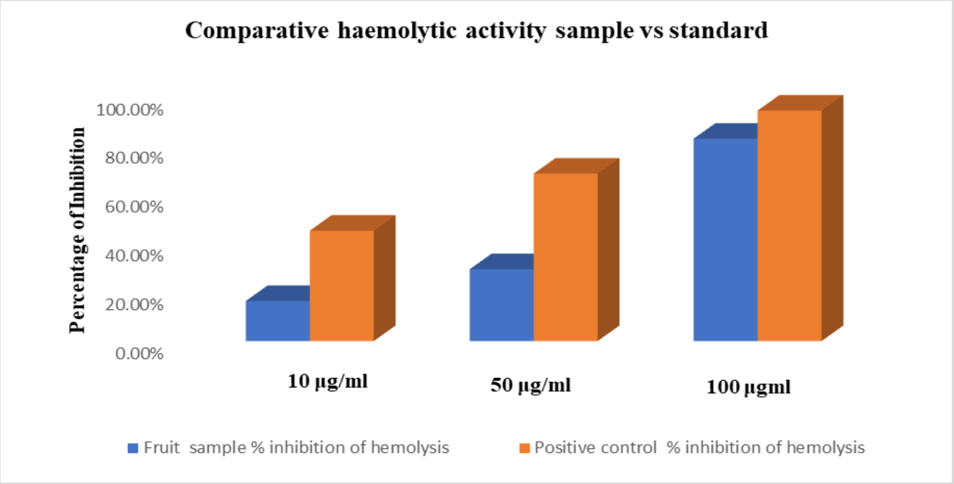

Figure 4. Concentration-dependent antihemolytic activity of fruit extract compared with standard

The antihemolytic activity of the fruit extract was assessed at different concentrations using the HRBC membrane stabilization method. As shown in Table 1 and Figure 4, the extract exhibited a concentration-dependent increase in membrane stabilization. The percentage inhibition of hemolysis increased from 16.39 ± 1.12% at 10 µg/mL to 82.71 ± 3.10% at 100 µg/mL. The positive control showed higher inhibition at all concentrations, ranging from 45.12 ± 2.05% to 94.20 ± 1.20%. The IC_{50} value of the extract was calculated as 66.08 µg/mL, indicating significant erythrocyte membrane stabilizing potential.

Statistical Analysis

Experiments were performed in triplicate (n=3), and results are expressed as mean ± SD. Statistical significance was determined using one-way ANOVA ($P<0.05$), and IC50 was calculated by linear regression.

Result

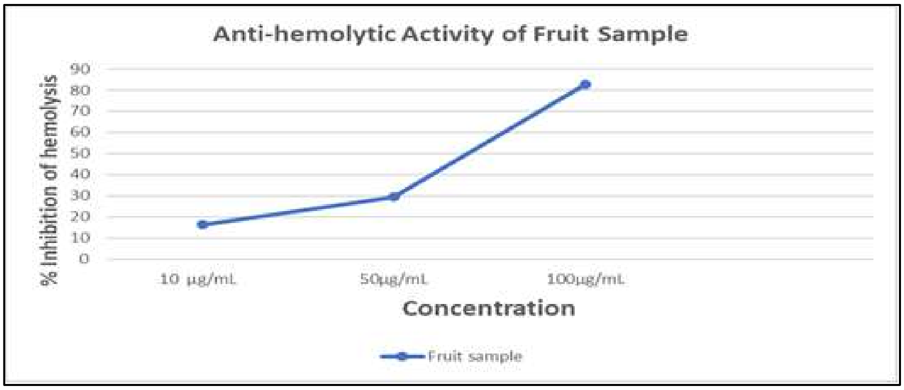

Figure 5. Dose-dependent antihemolytic activity of fruit extract showing percentage inhibition of hemolysis at different concentrations.

A concentration-dependent increase in antihemolytic effect was observed for the fruit extract. As shown in Figure 5, percentage inhibition of hemolysis increased progressively with increasing concentration, reaching maximum membrane stabilization at 100 µg/mL. The calculated IC_{50} value was 66.08 µg/mL, indicating substantial erythrocyte membrane protective potential.

Discussion

The present study revealed significant concentration-dependent antihemolytic activity of the fruit extract in the HRBC membrane stabilization assay, with maximum protection (82.71%) observed at a concentration of 100 µg/mL, with an IC50 of 66.08 µg/Ml Membrane stabilization under hypotonic stress suggests effective protection of erythrocytes against hemoglobin leakage. Although no previous reports are available on the antihemolytic activity of this fruit, earlier studies have documented strong antioxidant potential within the genus10. Oxidative stress is a key factor responsible for erythrocyte membrane damage, which may be reduced by the availability of bioactivity compounds7,8,9. These observations provide early scientific evidence supporting its cytoprotective potential. However, further in vitro and vivo studies are necessary to better understand its therapeutic applications.

Conclusion

The present study demonstrates that the fruit extract possesses significant, concentration-dependent antihemolytic activity by effectively stabilizing erythrocyte membranes under hypotonic stress conditions. The IC_{50} value of 66.08 µg/mL indicates substantial membrane protective potential. These findings provide preliminary scientific evidence supporting its cytoprotective relevance and justify further phytochemical characterization and in vivo investigations.

Ethical Considerations

Human blood samples were obtained from a certified diagnostic laboratory (Shri Ram Laboratory, Dapoli) after confirmation of donor health status. The samples were collected with informed consent from the donor and used strictly for in vitro research purposes. No invasive procedure was performed by the authors.

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Biomedical Sciences of *Adiantum* species

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Abstract

Adiantum species, commonly known as maidenhair ferns, belong to the Pteridaceae family and have been utilized in traditional medicine across various cultures for treating respiratory ailments, skin disorders, inflammation, and other conditions. This chapter reviews the biomedical sciences of key Adiantum species, focusing on their phytochemistry and validated pharmacological activities, including antimicrobial, antioxidant, anti-inflammatory, anticancer, and antidiabetic effects, as reported in recent studies up to 2025. Over 130 bioactive compounds, including flavonoids (rutin, quercetin, luteolin), phenolic acids (chlorogenic acid, and caffeic acid), and terpenoids, underpin these properties, with promising in vitro, in vivo, and in silico evidence. Despite low toxicity profiles, clinical trials remain scarce, highlighting the need for standardized extracts, mechanistic studies, and therapeutic formulations. Recent advancements in extraction techniques, like supercritical fluid extraction, enhance compound isolation for biomedical applications.

Keywords: *Adiantum*; fern; Western Ghats; Medicinal; Pteridophytes.

Introduction

Botanical Overview

The genus *Adiantum* comprises about 200 species of ferns, distributed in tropical and temperate regions worldwide, thriving in moist, shaded environments such as riverbanks and cliffs. Key medicinal species include *Adiantum capillus-veneris* (maidenhair fern) and *Adiantum philippense*, characterized by delicate, fan-shaped fronds on wiry black stipes arising from creeping rhizomes. These pteridophytes reproduce via spores and exhibit resilience to desiccation through adaptive leaf morphology. (Rastogi et al.; Qadir et al.)

Morphologically, *A. capillus-veneris* grows 15-75 cm tall with pinnate fronds 15-60 cm long, featuring round-oblong pinnae and marginal sori protected by reflexed edges. Traditional names vary: "Hansraj" in Ayurveda, "Pare-siavashan" in Iranian medicine, and "Shaar-ul-arz" in Arabic regions. Ethnopharmacologically, species treat cough, fever, wounds, hair loss, and digestive issues across Asia, Europe, and the Americas. (Pan et al.; Mou et al.; Rastogi et al.)

Traditional Uses

Adiantum species feature prominently in folk medicine for respiratory disorders like cough, bronchitis, and asthma, often as expectorants and demulcents. In Iranian traditional medicine, *A. capillus-veneris* addresses irregular menstruation, jaundice, splenomegaly, and skin/hair conditions. Ayurvedic uses include antiulcer, antidysenteric, and antitumor applications for A. philippense and others. (Akhter et al.; Pan et al.; Rastogi et al.; Qadir et al.)

Globally, decoctions treat diabetes, liver issues, microbial infections, and wounds; *A. capillus-veneris* promotes breastfeeding, renal function, and acts as an antiparasitic. Topical pastes manage dandruff and hair loss, while infusions serve as diuretics and febrifuges. These uses align with modern validations, bridging ethnomedicine and pharmacology (Rastogi et al.; Dehdari and Hajimehdipoor; Mou et al.)

Phytochemical Constituents

*Adiantum s*pecies yield diverse metabolites: flavonoids (quercetin, rutin, luteolin, kaempferol, astragalin), phenolic acids (chlorogenic, caffeic, ferulic, p-coumaric), triterpenoids (ursolic acid, filic-3-ene epoxide), phenylpropanoids, coumarins, phytosterols, fatty acids (hexadecanoic, linoleic), and saponins. (Akhter et al. 2023; Rastogi et al. 2018; Qadir et al. 2025)

Essential oils from *A. capillus-veneris* feature carvone (33%), carvacrol (15%), thymol, and hexahydrofarnesyl acetone, analyzed via GC-MS. HPLC-DAD-MS identifies high flavonoid content (4.66 mg CE/g DW), with quercetin-3-O-glucoside (949.5 μg/g) and 3,5-di-O-caffeoylquinic acid (769 μg/g). Minerals abound: K (17.95 mg/g), Ca (11.52 mg/g), Mg (2.90 mg/g). A. philippense shares quercetin, luteolin, and terpenoids like glycyrrhetinic acid. (Akhter et al.; Rastogi et al.)

Compound Class	**Key Examples**	**Species**	**Concentration/Source**
Flavonoids	Quercetin, Rutin, Luteolin, Kaempferol	*A. capillus-veneris, A. philippense*	Quercetin: 108.1 μg/g Rutin major

Phenolics	Chlorogenic acid, Caffeic acid, Ferulic acid	*A. capillus-veneris*	Chlorogenic: 60.9 µg/g; Ferulic: 183.8 µg/g
Terpenoids	Ursolic acid, Carvone, Filic-3-ene epoxide	Multiple	Carvone: 33% in EO
Fatty Acids	Hexadecanoic, Linoleic	*A. capillus-veneris*	7.02%
Minerals	K, Ca, Mg	*A. capillus-veneris*	K: 17.95 mg/g

These contribute to bioactivities via ROS scavenging and enzyme modulation (Rastogi et al.; Qadir et al.).

Extraction Techniques

Modern methods optimize bioactive recovery: hydrodistillation yields essential oils (0.55% v/w); Soxhlet extracts polyphenols; ultrasound-assisted (UAE) and microwave-assisted (MAE) target phenolics/flavonoids efficiently at low temperatures. Supercritical fluid extraction (SFE) isolates volatiles using green methods; RP-HPLC profiles carotenoids/chlorophylls. (Rastogi et al.)

Method	**Efficiency**	**Key Compounds**	**Advantages** **(Rastogi et al.)**
UAE	High	Saponins, Flavonoids	Short time, eco-friendly
MAE	Very High	Phenolics, Carotenoids	Fast, low solvent
SFE	Very High	Essential oils	Selective, green
Hydrodistillation	Moderate	Volatiles (carvone)	Traditional, simple

These surpass maceration, enabling scalable pharma applications. (Rastogi et al.)

Pharmacological Activities

Antioxidant Effects

Extracts scavenge DPPH radicals potently (IC50 0.039 mg/mL for EO), suppress H2O2-induced ROS, attributed to flavonoids/phenolics. *A. philippense* shows in vitro/in vivo antioxidant activity via quercetin. Reduces lipid peroxidation in cancer models. (Mou et al.; Viral et al.; Akhter et al.; Qadir et al.; Rastogi et al.)

Antimicrobial Activity

Methanolic extracts inhibit MDR bacteria (*S. aureus, E. coli, K. pneumoniae*) and fungi: highest against *S. aureus/Streptococcus*. Leaf methanolic fractions excel via membrane disruption. (Singh et al.)

Anti-inflammatory and Analgesic

Inhibits LPS-induced cytokines (TNF-α, IL-6, CXCL2) at 0.1 μg/mL; NF-κB pathway modulation. Quercetin/luteolin dock COX-2 (-8.1/-8.0 kcal/mol), stable in MD simulations for A. philippense. (Akhter et al.; Mou et al.; Qadir et al.)

Anticancer Potential

Hexane fraction of *A. capillus-veneris* yields IC50 21-26 μg/mL vs. HCT-116/A549/MCF-7; 82% EAC inhibition at 200 mg/kg. *A. venustum* reduces tumours via terpenoids/flavonoids. (Ayoub et al.)

Other Activities

Antidiabetic (α-glucosidase inhibition); wound healing (pro-migratory in HaCaT); hepatoprotective. Photodynamic synergy accelerates healing. (Mou et al.; Akhter et al.; Qadir et al.)

Toxicity and Safety

Studies show non-toxicity up to high doses; no histopathological changes in the liver/kidney. Subchronic trials confirm safety, though ALP monitoring is advised long-term. (Rastogi et al.; Bemidinezhad et al.)

Future Prospects

Standardised extracts, clinical trials, and nanoformulations (e.g., green synthesis) are needed. Molecular mechanisms, bioavailability studies, and combos with light therapy hold promise. Adiantum offers untapped biomedical potential against AMR, inflammation, and cancer.

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Anti-Inflammatory, Antioxidant and Antiulcerogenic Activity of *Solanum* Species: A Review

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Abstract

The genus *Solanum* represents one of the largest and most diverse groups of flowering plants, comprising nearly 1500–2000 species, including economically important crops such as potato, tomato, and eggplant. In recent years, increasing attention has been directed toward plant-derived compounds for the management of inflammatory and related disorders due to the limitations and adverse effects associated with synthetic drugs. *Solanum* species are rich sources of bioactive secondary metabolites such as alkaloids, flavonoids, phenolics, saponins, and sterols, which contribute to their pharmacological potential. Several species have demonstrated significant antioxidant, anti-inflammatory, and anti-ulcerogenic activities. This review compiles and evaluates the phytochemical constituents and biological activities of selected *Solanum* species, emphasizing their therapeutic relevance.

Introduction

The genus *Solanum*, belonging to the family Solanaceae, is one of the largest plant genera with wide distribution across tropical and subtropical regions. Many species are important in food and medicine. Increasing interest in plant-based therapies has emerged due to side effects of synthetic drugs

Inflammation and gastric ulcers are major health concerns. Conventional drugs like NSAIDs are effective but associated with adverse effects. Therefore, natural alternatives are being explored. *Solanum* species contain diverse phytochemicals such as alkaloids, flavonoids, and polyphenols which contribute to antioxidant, anti-inflammatory, and anti-ulcerogenic activities. This review highlights the therapeutic potential of Solanum species.

Plants of the genus *Solanum* are rich in bioactive compounds such as alkaloids, flavonoids, and polyphenols. These compounds are known to exhibit multiple biological activities, including antioxidant, anti-inflammatory, and gastroprotective effects. In addition to these, several studies have reported hepatoprotective, antidiabetic, antimicrobial, and immunomodulatory properties in various *Solanum* species.

For instance, *Solanum nigrum* has been traditionally used in Asian countries for the treatment of inflammation, edema, and infections. Phytochemical investigations have revealed the presence of glycoproteins, flavonoids, and triterpenoids, which contribute to its diverse pharmacological effects. Similarly, *Solanum xanthocarpum*, commonly known as Kantakari, is widely used in traditional medicine for its anti-inflammatory, expectorant, and digestive properties.

***Solanum* species**	**Part**	**Isolated compound**	**Metabolite concentration**	**Effect**	**References**
S. melongena	Root	Cannabisin D, Cannabisin F, Cannabisin G, Grossamide, Melongenamide B, Melongenamide C, Melongenamide D	IC50 values: 5.1.1 µM, 16.2 µM, 50.5 µM, 26 µM, 44.4 µM, 16.4 µM, 58.5 µM	Anti-inflammatory: reduced NO production in LPS-stimulated RAW 264.7 macrophages	**(Sun *et al.*, 2014)**
	Root	N-trans-Feruloyltyramine	IC50 value: 5.3 µM	Anti-diabetic: inhibits enzyme α-glucosidase	**(Liu *et al.*, 2011)**
	Peel	Saponins	1.2–9.9 mg	Anti-obesogenic: inhibits pancreatic lipase	**(Subandi *et al.*, 2019)**
S. torvum	Aerial	Torvoside M	IC50 value: 25.2–34.2 µg/mL	Anti-cancer: cytotoxic activity against MGC-803, HepG2, A549, MCF-7	**(Lu *et al.*, 2009)**
	Aerial	Neochlorogenin glycoside	IC50 value: 2.87 µM	Anti-neutrophilic inflammatory activity	**(Lee *et al.*, 2013; Ma *et al.*, 2017)**

	Fruit	Steroidal glycosides	IC50 values: 30–260 µM	Anti-cancer activity against melanoma cells	**(Li *et al.*, 2014)**
	Root	Torvanol A	IC50 value: 9.6 µg/mL	Antiviral activity against HSV-1	**(Arthan *et al.*, 2002; Mohan *et al.*, 2013)**
	Seeds	Torvanol A	10–30 mg/kg	Antidepressant and anxiolytic activity	**(Mohan *et al.*, 2013)**
	Fruit	Methyl caffeate	3 mg/mL	Antiproliferative activity	**(Balachandran *et al.*, 2015; Balachandran *et al.*, 2012; Gandhi *et al.*, 2011; Takahashi *et al.*, 2010)**
S. cernuum	Leaf	Cycloeucalenone, 24-oxo-31-norcycloartanone	300–600 mg/kg	Analgesic and anti-inflammatory activity	**(Lopes *et al.*, 2014)**
S. lyratum	Whole	Solajiangxin A-C	ED50 value: 1.9–3.7 µg/mL	Anti-cancer activity	**(Yao *et al.*, 2013)**
S. septemlobum	Whole	Septemlobin A-C	IC50 value: 3.8–7.5 µM	Anti-cancer activity	**(Zhang *et al.*, 2015)**
S. anguivi	Fruit	Gallic acid, chlorogenic acid, caffeic acid, rutin, quercetin	Various concentrations	Antioxidant activity	**(Elekofehinti *et al.*, 2013)**
S. betaceum	Fruit	Keracyanin, pelargonidin 3-rutinoside, tulipanin	Not specified	Antioxidant activity	**(Hurtado *et al.*, 2009; Osorio *et al.*, 2012)**

S. elaeagnifolium	Aerial	Kaempferol-8-C-β-D-galactoside	25–75 g/kg	Hepatoprotective activity	**(Hawas *et al.*, 2013)**
S. americanum	Aerial	N-trans-p-coumaroyloctopamine, N-trans-p-coumaroyltyramine	IC50 values: 2.3 μM, 2.7 μM	α-glucosidase inhibition	**(Silva *et al.*, 2017)**
S. capsicoides	Seed	Carpesterol	GI50: 24–32 μg/mL	Antiproliferative activity	**(Petreanu *et al.*, 2016)**

Table 1: Phytochemicals of Solanum species and their biological effects.

These findings indicate that Solanum species serve as valuable sources of pharmacologically active compounds with diverse therapeutic applications.

Economic and Medicinal Importance

The genus *Solanum* includes several economically important food crops such as *S. tuberosum* (potato), *S. lycopersicum* (tomato), and *S. melongena* (eggplant). In addition to their nutritional value, many species are used in traditional medicine. Some species are also cultivated for ornamental purposes, reflecting the wide diversity within the genus. The integration of traditional knowledge with modern scientific research has further emphasized the importance of Solanum species in drug discovery and development.

Conclusion

Solanum species are rich in bioactive compounds with significant therapeutic properties. Their antioxidant, anti-inflammatory, and anti-ulcerogenic activities support their traditional use. Further studies are required to validate clinical efficacy and develop standardized formulations.

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Female Infertility and Traditional Medicinal Plants: An Overview of the New Findings

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Abstract

Female infertility is a complex health issue that affects a significant number of women of reproductive age across the globe. Although modern techniques such as assisted reproductive technologies are available, they are often expensive and may not always provide successful outcomes. Traditional medicinal plants are gaining attention as supportive therapies because they act through multiple biological pathways, including hormonal balance, antioxidant defense, and reduction of inflammation. This chapter highlights the major causes of female infertility, the role of medicinal plants, their active constituents, and their mechanisms of action.

Keywords: Female infertility, medicinal plants, phytoestrogens, antioxidants, PCOS, herbal medicine.

Introduction

Infertility is generally described as the inability to achieve pregnancy even after one year of regular, unprotected intercourse. Among all infertility cases, female factors contribute to nearly half. This condition arises due to a combination of hormonal disturbances, physiological abnormalities, and environmental influences.

Although techniques like IVF have improved success rates, they remain costly and are not easily accessible to everyone. Therefore, increasing attention is being given to traditional medicinal systems such as Ayurveda and Traditional Chinese Medicine. These systems utilize plant-based remedies that work on multiple targets within the body, making them useful in managing complex disorders like infertility.

Role of Traditional Medicinal Plants

Traditional medicinal plants play a significant role in improving female fertility. Modern research shows that these plants act through multiple biological mechanisms rather than a single pathway. They influence hormones, cellular processes, and reproductive tissues simultaneously, making them effective in managing infertility.

Hormonal Regulation (HPO Axis Modulation)

The female reproductive system is regulated by the hypothalamic–pituitary–ovarian (HPO) axis, which controls hormones such as GnRH, FSH, LH, estrogen, and progesterone. Disturbances in this system lead to irregular menstrual cycles, anovulation, and infertility. Many medicinal plants contain phytoestrogens that mimic estrogen and bind to its receptors, helping to regulate hormone secretion and normalize ovulation.

For example, Vitex agnus-castus reduces prolactin through dopaminergic action, Foeniculum vulgare supports hormonal balance, and Phoenix dactylifera enhances gonadotropin secretion. These plants help restore endocrine balance and improve ovarian function, particularly in conditions like PCOS.

Antioxidant Protection (ROS Reduction)

Oxidative stress occurs when reactive oxygen species (ROS) damage ovarian follicles, oocytes, and DNA, leading to reduced fertility. Medicinal plants are rich in flavonoids, polyphenols, and carotenoids, which act as natural antioxidants. These compounds neutralize ROS, activate protective pathways such as Nrf2, and prevent cellular damage. As a result, they improve oocyte quality and reproductive outcomes in both natural and assisted reproduction.

Anti-inflammatory Action

Chronic inflammation negatively affects ovulation, implantation, and uterine health, and is strongly associated with conditions like PCOS and endometriosis. Medicinal plants exhibit anti-inflammatory properties by reducing cytokines and inflammatory markers. For instance, Nigella sativa contains thymoquinone, which reduces inflammation, while other plants help restore ovarian function and improve reproductive health.

Endocrine System Modulation

The endocrine system plays a central role in regulating reproductive hormones. Disorders such as insulin resistance, thyroid imbalance, and hyperprolactinemia can impair fertility. Medicinal plants help regulate hormone receptors, neurotransmitters, and metabolic pathways. They improve insulin sensitivity, control prolactin levels, and influence neurotransmitters such as dopamine and serotonin.

For example, Vitex agnus-castus regulates prolactin levels, while Crocus sativus supports endocrine balance. Overall, phytochemicals help restore hormonal signaling and improve fertility, particularly in metabolic disorders like PCOS.

Bioactive Compounds in Medicinal Plants and Their Role in Female Infertility

Medicinal plants contain a wide variety of bioactive compounds (also called phytochemicals) that are responsible for their therapeutic effects. These compounds act on hormones, cells, enzymes, and molecular pathways involved in female reproductive health.

The most important groups of bioactive compounds include Flavonoids, Alkaloids, Terpenoids and Phenolic compounds.

1. Flavonoids (Antioxidant + Estrogen-like Action)

Flavonoids are natural compounds found in many medicinal plants, fruits, and vegetables. They are especially important for female fertility because they Protect eggs (oocytes) and help balance hormones.

2. Alkaloids (Neuroendocrine Effects)

Alkaloids are nitrogen-containing compounds that mainly affect the nervous system and hormone regulation. They play a key role in controlling brain signals (hypothalamus).

3. Terpenoids (Anti-inflammatory Action)

Terpenoids are a large group of plant compounds responsible for Anti-inflammatory and Hormone-supporting effects. They are especially useful in conditions like PCOS and Endometriosis. Terpenoids reduce inflammation via NF-κB inhibition (Abdallah et al., 2023)

4. Phenolic Compounds (Free Radical Scavenging)

Phenolic compounds are strong antioxidants found in medicinal plants. They protect reproductive cells from damage and aging. Phenolics improve oocyte quality and delay ovarian aging (Wang et al., 2023). Strong antioxidant activity protects reproductive tissues (Frontiers in Nutrition, 2025). Resveratrol improves fertility outcomes in experimental models (PubMed, 2020)

Bioactive compounds in medicinal plants play a central role in improving female fertility. Restore hormonal balance, protect ovarian cells, reduce inflammation and improve overall reproductive health.

Compound Type	Main Function
Flavonoids	Antioxidant + estrogen-like
Alkaloids	Neuroendocrine regulation
Terpenoids	Anti-inflammatory
Phenolics	Free radical scavenging

Medicinal Plants, Active Compounds, Mechanisms and Functions

Medicinal plants used in female infertility contain specific bioactive compounds that act through distinct biological mechanisms. These mechanisms target major causes of infertility such as hormonal imbalance, oxidative stress, inflammation, and metabolic disorders like PCOS.

Table showing plants with active compound and their functions

Plant	**Active Compound**	**Mechanism of Action**	**Physiological Function in Infertility**
Asparagus racemosus	Shatavarins (steroidal saponins)	Bind to estrogen receptors (ERα, ERβ); mimic estrogen; regulate HPO axis	Stimulates follicular development and improves ovulation
Withania somnifera	Withanolides	Reduces cortisol via HPA axis; improves neuroendocrine signaling	Restores hormonal balance and reduces stress-induced infertility
Vitex agnus-castus	Flavonoids (casticin)	Activates dopamine D2 receptors → inhibits prolactin secretion	Reduces hyperprolactinemia and supports ovulation
Nigella sativa	Thymoquinone	Scavenges ROS; activates antioxidant enzymes; reduces oxidative stress	Protects ovarian follicles and improves oocyte quality
Curcuma longa	Curcumin	Inhibits COX-2 and NF-κB pathways; reduces inflammatory cytokines	Improves uterine environment and implantation success
Trigonella foenum-graecum	Diosgenin (steroidal saponin)	Activates insulin signaling pathways; improves glucose uptake; reduces insulin resistance	Regulates PCOS, lowers androgen levels, restores ovulation

This table clearly shows that each plant has a specific target pathway. Together, they provide a multi-target therapeutic approach.

Conclusion

Traditional medicinal plants provide a promising complementary approach to female infertility management. Their multi-target mechanisms, including hormonal regulation and antioxidant protection, make them effective. However, further research is necessary to establish standardized treatment protocols.

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Cullen corylifolium (L.) Medik: A Multifunctional Medicinal Weed with Emerging Therapeutic Significance

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Abstract

Cullen corylifolium (L.) Medik, a member of the Leguminosae, commonly known as Babchi, is an well-known medicinal plant that is found throughout tropical and subtropical areas, particularly in India. Babchi, a weed found in fallow lands and field margins, has become extremely valuable in both classical and modern medicinal approaches because of its own rich reservoir of bioactive chemicals. Its seeds are used as medicine. Babchi is said to have a number of biological properties reported for various biological activities, such as skin disorder treatment, antioxidant, antimicrobial, anti-inflammatory, anti-aging and antibacterial. The plant is a hardy and adaptable species that thrives in arid dry wastelands, roadsides and agricultural fields. In addition, this chapter is expected to enhance interest in Babchi and could contribute to the development of novel formulations with improved therapeutic potential.

Keywords: Medicinal, Babchi, bioactive, skin disorder

Introduction

Plants have long been central to traditional medicine and continue to offer new therapeutic potential. Their renewed popularity is due to effectiveness and fewer side effects compared to synthetic drugs [6]. According to WHO, about 80% of the global population relies on plant-based medicines for primary healthcare, especially in rural and tribal areas [1].

Cullen corylifolium (L.) Medik., commonly known as Babchi, is a significant medicinal plant widely used in treating skin disorders such as leucoderma, psoriasis, leprosy, and pruritus [1][6]. Its seeds are particularly valued and contain bioactive compounds like psoralen, isopsoralen, bakuchiol, and flavonoids [2]. Psoralen stimulates melanin production under sunlight, aiding skin treatment [3].

The plant is extensively used in Ayurveda and Unani systems for various therapeutic purposes [1]. This chapter highlights its ethnobotany, phytochemistry, traditional uses, and pharmacological importance [2].

Botanical Taxonomic Classification

Kingdom : Plantae

Division/Phylum: Angiosperms / Angiospermae
Class : Eudicots / Dicotyledoneae
Order : Fabales / Rosales
Family : Fabaceae (Leguminosae)
Subfamily : Faboideae / Papilionaceae
Genus : *Cullen*
Species : *Cullen corylifolium* (L.) Medik.

Fig. Morphological characters of *Cullen corylifolium* (A) *C. corylifolium*: Twig showing flower and stem (B) *C. corylifolium*: Leaf (C) *C. corylifolium*: Mature fruits with one seeded pods (D) *C. corylifolium*: Dry pods (legumes) (E) *C. corylifolium*: Seeds

Botanical Description: Babchi is an erect annual herb belonging to the family Fabaceae. The plant grows up to 95 cm tall, with grooved stems and branches that are conspicuously gland-dotted and bear a few appressed hairs.

Leaves: Leaves are broadly ovate-elliptic, measuring 3.5–11 × 2.5–9 cm. They are gland-dotted, with a cuneate or rounded base, inciso-dentate margins, and a mucronate apex. Both surfaces are hairy and nigro-punctate. Petioles are about 1 cm long, hairy, and also gland-dotted; stipules are lanceolate and persistent.

Flowers: Inflorescences are dense, short, axillary racemes bearing bluish-purple flowers on very short pedicels. The calyx is hairy on the outside, with upper teeth linear-lanceolate and lower teeth ovate, the latter being twice as long as the upper. The corolla is twice the length of the calyx.

Pods: 8 mm across, ovate-oblong, compressed, black, punctate; seeds smooth, adhering to the pericarp. Common, in black soil wastelands.

Phytochemical Constituents: Babchi seeds are a treasure of secondary metabolites responsible for its therapeutic effects.

Sr. No.	Compound Group	Important Constituents	Medicinal Role
1	Furocoumarins	Psoralen, Isopsoralen	Skin disorders treatment
2	Flavonoids	Bavachin, Bavachalcone	Antioxidant, antimicrobial
3	Coumarins	Psoralidin	Anti-inflammatory
4	Essential oils	Volatile aromatic compounds	Antimicrobial
5	Meroterpenes	Bakuchiol	Anti-aging, antibacterial

Bakuchiol is particularly noteworthy and is now widely used in dermatological and cosmetic formulations worldwide as a natural alternative to retinol. The coumarin components include psoralenoside, isopsoralenoside, psoralen, isopsoralen and prosalidin [2]. The main flavonoid components are bavachin, neobavaisoflavone and isobavachalcone. Psoralen, isopsoralen, corylifolin, corylin and psoralidin [2].

Phytochemistry: The chemical constituents of the fruit include isoflavones and corylinin, along with six known compounds: isopsoralen, psoralen, sophoracoumestan A, neobavaisoflavone, and daidzin. Additionally, the fruit contains corylinal, neobavaisoflavone, the methyl esters of two compounds, psoralenol, 5′-formyl-2′,4-dihydroxy-4′-methoxychalcone, and bavachromanol. The essential oil contains various chemical constituents, including α-elemene, γ-elemene, β-caryophyllenoxide, limonene, 4-terpineol, linalool, and geranyl acetate [4].

Pharmacological Properties

This plant is also pharmacologically studied for its anti-leucoderma activity, anti-acne activity, anti-psoriatic activity, anti-eczema activity, antibacterial activity, Antifungal activity, antiviral activity, antioxidant activity, anthelmintic activity, insecticidal and genotoxic activity, protective effect against retinal damage, anti-Alzheimer activity, antidepressant activity, anti-diabetic activity, antiprotozoal activity, anti-obesity activity, immunomodulatory activity, anti-cancer activity and neuroprotective activity [1].

Traditional Uses

- Effective in skin diseases like leucoderma, psoriasis, eczema, and infections [6]
- Used for blood, digestive, respiratory, and bilious disorders [1]
- Helps in asthma, cough, diabetes, and constipation [3]
- Exhibits antibacterial, antifungal, anthelmintic, diuretic, and laxative properties [7]
- Seeds and oil applied in topical treatments, especially for vitiligo; psoralen promotes pigmentation [2][3]
- Acts as a blood purifier and improves skin, hair, and nails [6]
- Useful in wounds, ulcers, inflammation, and kidney or bone disorders [2]
- Supports reproductive health and shows anticancer and hepatoprotective effects [6]

Agricultural and Economic Importance

In dryland regions, Babchi can be grown as a valuable therapeutic crop while being frequently considered a weed. It can thrive in drought circumstances and requires very little in the way of agricultural inputs. Babchi is becoming more and more popular in the cosmetics and natural medicine sectors. Additionally, farmers in rural areas have a strong chance of making money from its cultivation.

Propagation / Cultivation

The crop is established by direct sowing, requiring about 8 kg seeds per hectare without pre-treatment. Sowing is done before the monsoon after proper land preparation. Seeds are planted at 60 × 30 cm spacing with basal NPK (60:60:30 kg/ha) and farmyard manure application. Regular weeding and limited irrigation ensure good growth under rainfed conditions. The crop matures in 7–8 months, with multiple harvests between December and March. It can also be propagated through tissue culture methods [4][6].

Safety and Precautions

Despite its benefits, Babchi should be used cautiously. Psoralens may cause photosensitivity and skin irritation, while excessive doses can affect liver and kidney health, alter urine color, and lead to hyperacidity or gastritis. Adverse effects like nausea and vomiting have also been reported [4]. It should be taken in recommended doses under medical supervision, especially during pregnancy, lactation, and in children. Certain foods are advised to be avoided during treatment [4].

Conclusion

C. corylifolium is widely used for treating leukoderma, psoriasis, vitiligo, asthma, ulcers, and kidney disorders, and also acts as an aphrodisiac and anti-inflammatory. It contains bioactive compounds like essential oils, coumarins, alkaloids, flavonoids, and terpenoids, with proven pharmacological value. With proper validation, cultivation, and standardization, it can become an effective herbal drug. Its potential in cosmeceuticals, along with possible anticancer and neuroprotective applications, highlights its future importance.

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An Innovative Approach Through Herbal Medicines

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Abstract

Plants consist of many metabolites called phytochemicals which are potential source of herbal medicines. Many popular plants are used in preparation of innovative herbal medicines which are safer, consistent and show best results without any side effects. These innovations allow expansion of medical treatments, integrating natural compounds into modern pharmacy and biotechnology to improve health and reduce the reliance on purely synthetic drugs. The innovative approach through use of herbal medicines can be boon to medical field and treatments to human ailments for better and healthy future.

Introduction

Plants have been an important biotic component of the Biospere. All of our basic needs are fulfilled by plants and they constitute a part of a balanced diet because they include essential nutrients including fibres, minerals and vitamins for proper metabolic functions of the body. The overall immunity and health issues like chronic illness, diabetes, cancer, heart diseases can be improved by incorporating a variety of plant-based foods into our daily diets (Grinde, B., & Patil, G. G. 2009). Plants supply vital nutrients as well as have the ability to prevent and cure a number of illnesses. Plants have been utilized for ages to promote healing and reduce the symptoms of illness. Many ancient and contemporary medical systems still heavily rely on plant-based therapies. It has been demonstrated that the herbs lessen depression, anxiety, and tension and can improve our productivity, creativity, and cognitive abilities. (Niazi P. et al., 2023).

Since prehistoric times, the medicinal plants also called herbs, have been found and utilized in conventional medical procedures. Herbal plants are crucial for both preventing and curing human illnesses. Many civilizations and tribals since ancient times, rely on plant-based products as medicines for treatments of different ailments. Plant based therapies make about 85% of the traditional medicnes which accounts for 40% of the health care worldwide. The plants produce variety of matebolites called phytochemicals which play an important role in drug discovery. These metabolites also help in defence against pathogens like bacteria, fungi, insects and herbivorous mammals. It is reported that many of native communities use 6500 plant species as traditional medicine and there are about 50,000 known floral species around the globe, documented as traditional medicine which are exploited by the pharmaceutical industries to create safer, better medications. Thus, plants are promising source for novel herbal medication.

The plant-based medicines are natural and new techniques are employed to extract various useful phytochemicals and use them in modern biotechnological procedures to create effective herbal products. Plants are important in scientific research and medical treatment including traditional herbal medicines to contemporary pharmacological discoveries. The plant based bioactive compounds may be used to develop new drugs and therapies for a range of ailments as a source for drug development, biomanufacturing and personalized treatment. They provide phytochemicals for new safer drugs that can be anti-cancerous, anti-diabetic or anti-malarial and have the potential to create novel medicines for treatments of variety of illnesses. Medicinal plants complement conventional therapies, offering sustainable, cost effective and natural treatment solutions. The recent times the innovation in herbal medicines include the use of gentically engineered plants that produce vaccines, antibodies and therapeutic proteins. The phytochemicals are used to develop new herbal drugs that have less side effects. E.g the ginger plants are used to alleviate side effects of conventional, intense treatments in dreaded diseases like cancer. The plants like ashwagandha and turmeric have become essential parts of global supply chains for managing stress and immunity. The discovery of particular plant derived lead molecules for cancer therapy and neurological illnesses has been positive. It could be possible due to developments in metabolomics and bioinformatics. Researchers use plants like tobacco, maize, and potatoes as "bioreactors" to produce recombinant antigens and plant-based vaccines.

Medicinal plants remain a vital source of novel drug discovery and motivation for medical studies. Researchers investigate conventional treatments and local experience to discover possible bioactive substances that could result in the creation of innovative treatments for different illnesses encompassing cancer, infectious diseases, and long-term ailments (Gurib-Fakim, 2006). It means plant-based medicines have been a potential curator of ailments as known since Ayurveda. This science is based on plant products ranging from ark to kada and shown the importance of different herbs / plant materials either singly or in combinations. In recent era, the application of scientific understanding, data evaluation, sophisticated methods and technology has enabled industries to extract and produce numerous active compounds from plants for the formulation of pharmaceutical drugs. Notably, a large number of prescription and over-thecounter medications are derived from plant compounds (Farnsworth et al, 1985). Many plants are extensively researched, investigated in preparation of innovative herbal medicines which are much safer, consistent and show best results and used for their medicinal qualities. Some of herbs include:

- **Aloe Vera:** Soothing, cool effect and used in the treatment of damaged skin, wounds and burns.
- **Garlic:** Potent antibacterial qualities and is used to strengthen the immune system and promote cardiovascular health.
- **Ginger:** Used for nausea, pain relief and cold treatment.
- **Ashwagandha:** Used for reducing stree, anxiety and improving energy.
- **Shatavari:** Supports female reproductive health, balance hormones, boost immunity and reduce stress.
- **Giloy:** Immunomodulatory, antioxidant, and anti-inflammatory properties to treat fever, diabetes, infections, and skin diseases.
- **Amla:** Boosts immunity, aid digestion and reduce inflammation.
- **Lavender:** Soothing perfume and is used in aromatherapy to ease anxiety and encourage relaxation.
- **Turmeric:** Contains active ingredient curcumin, which has anti-inflammatory, antiseptic and antioxidant qualities.

Conclusion

The herbal medicines are prepared by incorporating natural pytochemicals into contemporary pharmacy and biotechnology. It helped in the growth of medical therapies improving health indices and lowering the dependency on synthetic medications. Plant molecular farming for vaccine production and the application of nanotechnology to improve the bioavailability of chemicals obtained from plants are examples of innovations. The phytoconstiuents like curcumin and berberine are being integrated into lipid- based nanoparticles and liposomes using biotechnological techniques.

Better monitoring, isolation and detection in the production of active herbal medications can be achieved through the use of computer software, data interpretation, new extraction techniques and artificial intelligence technologies.

The innovative approach through use of herbal medicines can be boon to medical field and treatments to human ailments for better and healthy future. The future generations will continue to profit from the wonders of medicinal plants or herbal remedies with therapeutic potential by adopting sustainable methods, conservation initiatives and creative approaches.

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Barleria as a Platform for Innovation in Science and Technology: From Botanical Diversity to Translational Drug Discovery

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Abstract

The integration of traditional botanical knowledge with modern scientific and technological tools has become a major driver of innovation in contemporary life sciences. The genus *Barleria* L. (family Acanthaceae) exemplifies this convergence by combining taxonomic diversity, chemical complexity, and emerging technological applications in drug discovery. Distributed mainly across Africa, the Indian subcontinent, and Southeast Asia, *Barleria* comprises approximately 250–300 species with wide ecological adaptability and long-standing ethnomedicinal relevance (Balkwill & Balkwill, 1998; Darbyshire et al., 2010; McDade et al., 2018).

Recent advances in phytochemistry, mechanistic pharmacology, and computational biology have revealed a rich repertoire of bioactive secondary metabolites, including iridoid glycosides, flavonoids, and terpenoids, with demonstrated anti-inflammatory, antimicrobial, antidiabetic, and hepatoprotective activities (Bawake & Gaykar, 2022). Computational approaches such as molecular docking, molecular dynamics simulations, and in silico ADMET prediction have accelerated lead identification and improved mechanistic understanding, highlighting the genus as a promising source of phytopharmaceutical candidates (Li et al., 2022; Patel et al., 2024).

Despite strong preclinical evidence, translational challenges persist, particularly in standardization, pharmacokinetic validation, and clinical evaluation. This manuscript presents *Barleria* as an innovative botanical model, illustrating how interdisciplinary integration of taxonomy, chemistry, pharmacology, and digital technologies can contribute to future science- and technology-driven therapeutic development.

Keywords: *Barleria*, Acanthaceae, iridoid glycosides, medicinal plants, pharmacological activity, molecular docking, phytochemistry.

Introduction

Innovation in science and technology increasingly depends on interdisciplinary approaches that bridge traditional knowledge systems with modern analytical and computational tools. Medicinal plant research has evolved beyond descriptive ethnobotany into a data-driven discipline integrating molecular biology, bioinformatics, and pharmaceutical sciences (McDade et al., 2018; Li et al., 2022). Within this context, the family Acanthaceae has gained prominence due to its taxonomic richness and chemical diversity (Balkwill & Balkwill, 1998; Darbyshire et al., 2010). Among its members, the genus *Barleria* stands out as a scientifically valuable and technologically adaptable system for studying plant-derived bioactive compounds.

Historically, species of *Barleria* have been used in traditional medicine for treating inflammatory disorders, infections, metabolic diseases, and liver ailments (Bawake & Gaykar, 2022). Modern scientific investigations have validated many of these uses, providing mechanistic insights that align with contemporary drug discovery paradigms (Patel et al., 2024). The genus therefore represents an opportunity to translate biodiversity into innovation by applying advanced scientific methodologies.

Taxonomic and Biological Diversity as an Innovation Resource

Taxonomic diversity is a foundational resource for scientific innovation, as it expands the chemical and functional space available for therapeutic exploration (McDade et al., 2018; Darbyshire et al., 2010). *Barleria* includes perennial herbs, undershrubs, and woody shrubs adapted to a wide range of ecological conditions (Balkwill & Balkwill, 1998; Darbyshire et al., 2010). Morphological traits such as bilabiate corollas, specialized bracts, and efficient seed dispersal mechanisms reflect adaptive evolution and ecological resilience (Scotland & Vollesen, 2000; McDade et al., 2018).

This biological diversity has direct technological relevance. Species-level variation influences metabolite composition, enabling comparative phytochemical studies and chemotaxonomic classification (Bawake & Gaykar, 2022; McDade et al., 2018). Advances in molecular systematics and phylogenetic analysis further support precise species identification, reducing ambiguity in pharmacological research and enhancing reproducibility—an essential requirement for translational science (Li et al., 2022; Patel et al., 2024).

Phytochemical Architecture and Technological Characterization

The phytochemical profile of *Barleria* species is dominated by structurally diverse secondary metabolites, notably iridoid glycosides, flavonoids, phenolic acids, and terpenoids (McDade et al., 2018; Bawake et.al., 2024). These compounds are biosynthesized through conserved metabolic pathways, yet display species-specific modifications that influence biological activity (Li et al., 2022).

Technological innovations in chromatography, spectroscopy, and metabolomics have significantly improved the characterization of these compounds (Patel et al., 2024). High-performance liquid chromatography coupled with mass spectrometry enables rapid metabolite profiling, while nuclear magnetic resonance spectroscopy supports structural elucidation (Li et al., 2022; Patel et al., 2024). Such tools transform complex plant extracts into chemically defined systems suitable for mechanistic and computational analysis (Li et al., 2022).

Iridoid glycosides are particularly significant due to their multi-target biological activity (Bawake & Gaykar, 2022). Their molecular frameworks allow interaction with enzymes, transcription factors, and signaling proteins, making them attractive scaffolds for drug development (Li et al., 2022; Patel et al., 2024). The coexistence of multiple bioactive classes within *Barleria* also suggests synergistic effects, an emerging concept in systems pharmacology (Patel et al., 2024).

Mechanistic Pharmacology and Multi-Target Actions

A defining feature of *Barleria*-derived compounds is their ability to modulate multiple biological pathways simultaneously (Li et al., 2022). Experimental studies demonstrate strong anti-inflammatory effects mediated through suppression of pro-inflammatory mediators and regulation of oxidative stress pathways (Atanasov et al., 2021; Patel et al., 2024). These actions are particularly relevant in chronic disorders where single-target drugs often show limited efficacy (Li et al., 2022).

Antimicrobial activity observed in several *Barleria* species highlights another dimension of innovation (Bawake et.al.,2024). Plant-derived multi-component systems can interfere with microbial membranes, enzymes, and signaling mechanisms, offering potential solutions to antimicrobial resistance (Patel et al., 2024). Similarly, inhibition of carbohydrate-metabolizing enzymes and protection of pancreatic and hepatic tissues underpin the antidiabetic and hepatoprotective effects associated with the genus (Li et al., 2022; Chen et al., 2023).

The emphasis on mechanism-based validation aligns *Barleria* research with modern pharmacological standards, moving beyond empirical observations toward evidence-based therapeutic development (Patel et al., 2024).

Computational Approaches and Digital Innovation

One of the most transformative innovations in contemporary science is the integration of computational technologies into natural product research (Li et al., 2022; Patel et al., 2024). In silico tools have become indispensable for screening, optimizing, and predicting the behavior of bioactive molecules (Li et al., 2022). In the case of *Barleria*, molecular docking studies have demonstrated strong binding affinities between key phytoconstituents and pharmacologically relevant targets, such as inflammatory enzymes and metabolic regulators (Li et al., 2022; Patel et al., 2024).

Molecular dynamics simulations further refine these findings by evaluating the stability and flexibility of ligand–protein complexes under physiological conditions (Li et al., 2022). Molecular dynamics simulations confirm structural stability of ligand–receptor complexes (Rodrigues et al., 2024). In parallel, ADMET prediction models provide early insights into absorption, distribution, metabolism, excretion, and toxicity profiles, reducing experimental costs and accelerating decision-making (Patel et al., 2024).

These digital tools position *Barleria* research firmly within the framework of science and technology innovation, illustrating how plant-based systems can be integrated into modern drug discovery pipelines (Li et al., 2022; Patel et al., 2024).

Translational Challenges and Opportunities

Despite substantial scientific progress, the translation of ***Barleria***-derived compounds into clinically approved products remains limited. Key challenges include variability in phytochemical composition, lack of standardized extraction protocols, and insufficient pharmacokinetic data (Patel et al., 2024). Addressing these issues requires technological solutions such as metabolomic fingerprinting, quality-by-design approaches, and nano-formulation strategies to improve bioavailability (Li et al., 2022; Patel et al., 2024).

Equally important is the need for well-designed preclinical and clinical studies that meet regulatory standards (Patel et al., 2024). Collaboration between botanists, chemists, pharmacologists, data scientists, and clinicians is essential to bridge the gap between laboratory research and real-world application (Li et al., 2022).

Future Perspectives

The future of *Barleria* research lies in its integration with emerging scientific technologies (Li et al., 2022; Patel et al., 2024). Systems biology approaches can elucidate network-level effects of complex phytochemical mixtures, while artificial intelligence and machine learning can identify novel structure–activity relationships (Patel et al., 2024). Sustainable cultivation, conservation genomics, and green extraction technologies further align *Barleria*-based research with global innovation and sustainability goals (McDade et al., 2018).

By positioning biodiversity as a source of technological advancement, *Barleria* serves as a model for innovation-driven natural product research (Darbyshire et al., 2010; McDade et al., 2018).

Conclusion

The genus *Barleria* represents a compelling intersection of botanical diversity, chemical innovation, and technological advancement. Through the application of modern analytical, computational, and pharmacological tools, traditional medicinal knowledge associated with this genus can be transformed into evidence-based therapeutic opportunities. Although translational challenges remain, continued interdisciplinary integration positions *Barleria* as a valuable contributor to innovation in science and technology, particularly in the development of future phytopharmaceuticals.

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Evaluation of Solvent-Dependent Phytochemical Variation in *Plectranthus mollis* (Aiton) Spreng. and *Colebrookea oppositifolia* Sm.

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Abstract

Phytochemistry deals with the study of the chemical constituents present in plant parts many of which exhibit significant medicinal properties. The family Lamiaceae is particularly rich in phenolic compounds and terpenoids. Members of this family possess notable antimicrobial, antioxidant, anti-inflammatory, and cardioprotective activities, making them valuable sources of natural alternatives to synthetic therapeutic agents. Identification of biologically active compounds begins with phytochemical screening of plant materials. In the present work, qualitative phytochemical analysis was on *Plectranthus mollis* (Aiton) Spreng. and *Colebrookea oppositifolia* Sm., were screened using five different solvents to identify the most suitable solvent for the extraction for further study in which ethanol and acetone show best solubility.

Keywords: Phytochemicals, Solvent, Extraction, Lamiaceae, *Plectranthus mollis* (Aiton) Spreng. and *Colebrookea oppositifolia* Sm.

Introduction

Plants contain numerous medicinally active chemical compounds known as phytoconstituents or phytochemicals, which also protect plants against microbial infestations. Major bioactive compounds include alkaloids, flavonoids, phenols, triterpenoids, glycosides, essential oils, and other secondary metabolites that contribute to plant physiological activities. In addition, primary metabolites such as carbohydrates, proteins, and lipids serve as food for humans (Kokate et al., 2002). A comprehensive study of crude drugs should therefore include both primary and secondary metabolites (Sofawora, 1982). The family Lamiaceae is rich in phenolic compounds and terpenoids with antimicrobial, antioxidant, anti-inflammatory, and antitumor properties. In this study, qualitative phytochemical screening of Plectranthus mollis and Colebrookea oppositifolia was conducted using petroleum ether, acetone, ethanol, chloroform, and water to evaluate solvent polarity and select suitable solvents for antioxidant compound isolation (Azzahra et al., 2026).

Material and Methods

The plants under study were collected, identified and then extract was prepared for further phytochemical analysis.

Collection of Plant Material

The selected plants were *Plectranthus mollis* (Aiton) Spreng., *Colebrookea oppositifolia* Sm. Plants were collected from different localities of Ahmednagar District, Maharashtra and identified from Botanical Survey of India, Western Circle, Pune.

Preparation of Plant Extract

The dried leaves were powdered by using grinder and used for extraction in different solvents as petroleum ether, chloroform, acetone, ethanol and water according to the polarity, by using Soxhelet apparatus. Crude extracts were collected and preserved for further experiment at 4^0C.

Preliminary Phytochemical Analysis

The phytochemical analysis of the extracts was tested for different phytochemicals present in leaves of selected plants by using standard procedures of Harbone (1973) and Trease Evans (2010).

- **Test for Carbohydrates (Molisch's Test):** In each 1 ml of plant extract, 3-5 drops of Molisch's reagent was added then 1ml concentrated H_2SO_4. Violet ring formation shows the presence of carbohydrates.
- **Test for Alkaloids (Wagner's Test):** Here test 1 ml of each plant extract was taken in test tube and acidified with 1.5% HCl. Then added of 3-5 drops of Wagner's reagent. Reddish brown precipitation indicates the presence of alkaloids.
- **Test for Flavonoids (Alkaline Reagent Test):** It is done with 1 ml sample of extract and 3-5 drops of 20% NaOH. Formation of yellow colour was appeared, becomes colorless after addition of 0.5 ml dilute HCl shows the presence of flavonoids.
- **Test for Phenol (Ferric Chloride Test):** The test is performed addition of $FeCl_3$ solution in 1 ml of each extract, deep blue colour developed. It indicated presence of phenol.
- **Test for Glycosides (Keller Kelliani Test):** 1 ml of each extract and 1 ml of glacial acetic acid mixed and 2-3 drops solution of $FeCl_3$ added. 0.5ml of concentrated H2SO4 added in it. Development of brown ring at the junction of two liquids confirms the presence of glycosides.
- **Test for Terpenoids (Salkowski Test):** In this test 1 ml of each plant extract

was treated with chloroform and conc. H_2SO_4 was added 3-5 drops of to it. Formation of reddish-brown precipitation seen at inner face conforms the presence of terpenoids.

- **Test for Saponins (Foam Test):** Here, 1 ml of each sample was mixed with 5 ml of water taken in the test tube and shaken vigorously, foam seen for 10-15 minutes, indicated the presence of saponins.
- **Test for Amino Acids and Proteins:** 2-3 drop of ninhydrin solution was added in each extract and kept in water bath for 1-2 minutes. Development of purple color indicates the presence of amino acids and proteins.
- **Test for Steroids (Salkowski Test)** 1ml of extract, was added in chloroform and followed by 3-5 drops of conc. H_2SO_4. Red color seen, indicated the presence of steroids.
- **Test for Quinones:** By adding 1 ml of each extract with 0.5 ml of conc. HCl, yellow precipitation appeared, it indicates presence of quinones.
- **Test for Resin:** 1 ml of extract was added in 5 ml water, the solution becomes turbid, indicating presence of resins.
- **Test for Coumarin:** During the test 1 ml of each sample was treated with 1.5 ml of 10% NaOH, yellow colour detected, confirms presence of coumarin.

Results and Discussion

The phytochemical profiling considers thirteen major phytochemicals like carbohydrate, alkaloids, phenolic compounds, tannins, glycosides, terpenoids, saponins, quinones, resin, coumarins and others which helps in understanding and linking various biological properties of these plants.

Plectranthus mollis **(Aiton) Spreng.**

Ethanolic and acetone extracts showed highest phytochemical diversity. Ethanol contained carbohydrates, alkaloids, flavonoids, phenolics, saponins, glycosides, proteins, and terpenoids, while acetone showed similar compounds with coumarins and quinones. Aqueous extract was moderate, petroleum ether limited, and chloroform least compatible. Results agree with Ramu et al. (2012) and Gunavathy and Sherin (2019).

Table 1: Phytochemical analysis of Plectranthus mollis (Aiton) Spreng.* and *Colebrookea oppositifolia S

SN	Plant Name	*Plectranthus mollis*					*Colebrookea oppositifolia*				
	Phytochemical	**PE**	**CH**	**AC**	**ET**	**AQ**	**PE**	**CH**	**AC**	**ET**	**AQ**
1.	Carbohydrates	-	-	+	+	+	+	+	-	+	+
2.	Alkaloids	+	+	+	+	-	+	+	+	+	+
3.	Flavonoids	-	+	+	+	+	-	-	+	+	+
4.	Phenolics	+	+	+	+	+	-	-	+	+	+
5.	Glycosides	+	+	+	+	+	+	+	+	+	+

6.	Terpenoids	-	-	+	+	+	+	+	+	+	+
7.	Saponins	+	-	-	+	-	+	+	-	+	+
8.	Amino acids and proteins	+	-	+	+	-	-	-	-	+	+
9.	Steroids	-	-	-	-	-	-	-	-	-	-
10.	Quinones	-	-	+	-	-	+	-	+	-	-
11.	Resins	-	-	-	-	+	-	-	-	-	-
12.	Coumarins	+	-	+	-	-	+	+	-	+	+

+ Present, - Absent, PE - Petroleum Ether, CH - Chloroform, AC - Acetone, ET - Ethanol, WR - Water.

Colebrookea oppositifolia **Sm.**

Ethanolic and aqueous extracts yielded maximum phytochemicals, including carbohydrates, alkaloids, phenolics, flavonoids, glycosides, saponins, terpenoids, proteins, and coumarins, indicating suitability for extracting compounds from *Colebrookea oppositifolia*. Acetone showed most constituents except alkaloids, saponins, and coumarins. Petroleum ether and chloroform contained fewer compounds. These findings agree with Sardar and Manik (2017) and Madhavan et al. (2011).

Conclusion

Twelve phytochemicals were detected in the studied plant extracts, while steroids were absent in both species. Among the solvents, ethanol proved most effective for phytochemical extraction, followed by water. Petroleum ether showed the least number of phytochemicals compared to other solvents.

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Nutritional Configuration of Finger Millets

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Abstract

Finger millet (*Eleusine coracana*), or ragi, is a resilient cereal widely grown in Africa and South Asia. Once considered an "orphan crop," it is now valued for food security in climate-stressed regions. Its grains are rich in complex carbohydrates, slowly digestible starch, and dietary fiber, supporting glycemic control. Protein levels are moderate but notable for methionine, an essential amino acid often lacking in other cereals. Finger millet also provides high calcium, iron, magnesium, phosphorus, and B-vitamins, making it effective against micronutrient deficiencies. Polyphenols and flavonoids add antioxidant benefits, reducing risks of chronic diseases. Traditional processing methods like fermentation and germination enhance nutrient bioavailability. With its nutritional strength and adaptability, finger millet is a strategic crop for sustainable diets.

Keywords: Finger millet; Nutritional composition; Micronutrient-rich cereals; Functional food; Sustainable food systems

Introduction

Finger millet (*Eleusine coracana*), known as ragi in South Asia and widely grown in Africa, is a traditional staple in semi-arid regions. Although often labeled an "orphan crop" due to limited research attention, it is gaining importance for its resilience, low input needs, and rich nutritional profile (Majumder et al., 2024). With increasing concerns about food insecurity, micronutrient deficiencies, and diet-related diseases, finger millet is recognized as a valuable, nutrient-dense, and climate-resilient crop (Mandavgane et al., 2026). Research highlights its strong nutritional composition and health benefits, supporting its role as a functional food (Kajla & Chaudhary, 2026). This chapter reviews its nutritional characteristics, including nutrient composition, phytochemicals, and health effects, along with factors influencing its quality and its potential integration into modern diets.

Macronutrients

Finger millet is predominantly composed of carbohydrates (65–75%), with a significant proportion of slowly digestible and resistant starch that supports glycemic control (Shobana et al., 2013). Its dietary fiber content (11–18%) is largely insoluble, aiding digestion, satiety, and cardiovascular health (Thakur, 2024). Protein levels range from 5.6–12.7%, notable for methionine, cysteine, and tryptophan, which improve protein quality compared to other cereals (Chandra et al., 2025). Lipid content is low (1–1.5%), but the presence of linoleic and oleic acids contributes to favorable fatty acid profiles and long shelf life (Singh & Upadhyay, 2026).

Micronutrients

Finger millet is exceptionally rich in minerals, especially calcium (344–450 mg/100 g), which is far higher than rice or wheat, making it valuable for bone health (Abioye et al., 2022). It also provides iron (3.9–5.4 mg/100 g), magnesium, phosphorus, and potassium, supporting metabolic and physiological functions (Obilana & Manyasa, 2002). In addition, finger millet contains B-group vitamins such as thiamine, riboflavin, niacin, pyridoxine, and folic acid, which are essential for energy metabolism and nervous system function (Shobana et al., 2013). Though moderate in quantity, these vitamins contribute meaningfully to dietary adequacy, especially in resource-limited diets.

Bioactive Compounds and Phytochemicals

Finger millet is particularly rich in polyphenols such as ferulic acid, catechins, tannins, and flavonoids, concentrated in the seed coat, which provide strong antioxidant activity and help reduce oxidative stress (Singh & Upadhyay, 2026). Its polyphenol content is higher than most cereals, contributing to disease-preventive effects (Rakkammal et al., 2024). The grain's high dietary fiber further supports gut health, glucose regulation, and cholesterol metabolism (Kajla & Chaudhary, 2026), while resistant starch enhances metabolic outcomes (Kumar et al., 2024). Although antinutritional factors like phytates and tannins may limit mineral absorption, they also provide antioxidant benefits, and traditional processing methods such as soaking, germination, and fermentation significantly improve nutrient bioavailability (Devi et al., 2014).

Challenges and Opportunities for Mainstreaming Finger Millet

Despite its dietary advantages, ragi remains underutilized in many regions due to factors such as limited consumer awareness, lack of processing infrastructure, and competition from higher-yielding cereals (Nirgude et al., 2020). Policy interventions, farmer education, and value chain development are needed to promote its wider adoption. Research and breeding efforts aimed at reducing antinutritional factors, improving grain yield and palatability, and developing convenient food products are critical to mainstreaming finger millet in contemporary diets (Gupta et al., 2017). Public health campaigns, school feeding programs, and integration into urban markets can further drive demand and support nutrition-sensitive agriculture.

Conclusion

Finger millet offers a compelling case for the integration of traditional crops with modern nutritional science and sustainable agriculture. Its exceptional mineral content, dietary fiber, bioactive compounds, and health-promoting properties position it as a "super grain" for the 21st century. As the world faces mounting challenges of food insecurity, malnutrition, and environmental stress, the promotion and mainstreaming of ragi can contribute significantly to nutritional security and sustainable food systems. Continued investment in research, breeding, processing technology, and policy support will be important for realizing the full potential of this remarkable cereal.

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Amaranthus cruentus: Nutrient Assessment and Expanding its Role Beyond Fasting Foods

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Abstract

Amaranthus cruentus, commonly known as *rajgira* (Marathi), is an ancient pseudocereal deeply rooted in Indian tradition, predominantly consumed during fasting periods. Its utilization in regular dietary pattern is limited in India. The aim here is to look beyond that conventional framing and explore the potential of *Amaranthus cruentus* as a nutritious pseudocereal suitable for year- round consumption. Based on nutritional evaluation backed by experimental data and existing literature, this chapter looks at what makes *rajgira* stand out is its strong macronutrient profile, good protein quality with notably higher lysine content compared to common cereals like *Triticum aestivum*, and the fact that it is naturally gluten-free, making it a suitable option for people with celiac disease or gluten intolerance. Additionally, its relatively low glycaemic index also makes it relevant for managing metabolic conditions through diet. Beyond its nutritional profile, this chapter also introduces new food preparations using amaranth that go beyond the traditional fasting preparations, demonstrating its adaptability to ever day culinary practice. By integrating nutritional data and practical food applications, this work presents *Amaranthus cruentus* as a functional and sustainable pseudocereal with significant potential in contemporary nutrition and food innovation strategies.

Keywords: *Amaranthus cruentus*, pseudocereals, nutritional evaluation, gluten-free grains, functional foods, food innovation.

Introduction

Amaranthus cruentus, popularly known as rajgira in India, occupies a distinctive place in traditional dietary customs, particularly during religious fasting (*vrat*). Botanically, it is classified as a pseudocereal because it does not belong to the grass family Poaceae, which includes staple cereals such as *Triticum aestivum* (wheat) and rice. Instead, it belongs to the family Amaranthaceae (Rastogi and Shukla, 2013). Owing to this botanical distinction, *rajgira* is culturally regarded as a "non-cereal" grain and is therefore permitted during fasting periods when conventional cereals are avoided.

Fasting practices in India often restrict grains believed to be heavy or difficult to digest. *Rajgira*, being light, energy-dense, and gluten-free, is considered suitable for sustaining energy levels without causing digestive discomfort. It is commonly consumed in the form of *laddoos, chikkis, puris*, and *rotis* during *Navratri* and other ritual observances. However, this strong association with fasting has confined its perception to a seasonal food, limiting its integration into everyday diets.

Nutritionally, *A. cruentus* exhibits superior protein quality, higher lysine content compared to wheat, significant dietary fiber, and valuable bioactive compounds (Mlakar et al. 2012; Rastogi and Shukla, 2013). Restricting it to fasting occasions represents nutritional underutilization. Therefore, this chapter evaluates its composition and explores its potential for broader, year-round dietary integration.

Proximate and Micronutrient Profile

Carbohydrate content was measured at 46% in grain and 43% in bread, indicating that amaranth remains a substantial energy source after processing. Fat content decreased from 9% in grain to 6.02% in bread, likely due to formulation adjustments and thermal treatment. Dietary fiber was recorded at 6% in grain and slightly higher at 6.7% in bread, suggesting favorable retention during product preparation.

Compared to conventional cereals such as *Triticum aestivum*, which typically contain 10–12% protein and lower lipid fractions, amaranth demonstrates superior protein concentration and appreciable healthy fat content. Literature reports protein levels ranging from 13–18%, closely aligning with the present findings (Alvarez-Jubete et al. 2010; Rastogi and Shukla, 2013).

Beyond macronutrients, amaranth is recognized for its micronutrient density, including iron, magnesium, phosphorus, calcium, and selenium, along with B-complex vitamins such as folate and vitamin B6. The presence of bioactive constituents such as squalene and phenolic compounds further enhances its functional relevance (Zhu, 2015; Kumar et al. 2018). Collectively, these attributes position *Amaranthus cruentus* as a nutritionally dense pseudocereal with significant potential for broader dietary incorporation.

3. Protein Quantity and Amino Acid Superiority

One of the most defining nutritional attributes of *Amaranthus cruentus* is its elevated protein concentration and superior amino acid balance. The present analysis recorded 17.3% protein in raw grain, positioning it above most conventional cereals. Literature reports protein levels ranging from 13–18%, validating its classification as a high-protein pseudocereal (Rastogi and Shukla, 2013).

Beyond quantity, protein quality is of greater nutritional importance. Unlike *Triticum aestivum*, which is limited in lysine, amaranth contains approximately 30–40% higher lysine content (Alvarez-Jubete et al. 2010). Lysine, an essential amino acid critical for growth and nitrogen balance, often limits the biological value of cereal-based diets. The improved lysine concentration enhances amino acid complementation and elevates Protein Digestibility Corrected Amino Acid Score (PDCAAS), indicating favorable digestibility and biological value.

These characteristics are particularly relevant for vegetarian populations and individuals with celiac disease, for whom amaranth serves as a nutritionally superior, gluten-free protein alternative.

4. Glycaemic Index and Metabolic Health Relevance

The glycaemic index (GI) of *Amaranthus cruentus* has been reported to be approximately 45, classifying it as a low to moderate GI food. In contrast, commonly consumed cereals such as *Triticum aestivum* and rice typically exhibit GI values around 70, producing higher postprandial glucose responses. Chaturvedi et al. (1997) demonstrated that grain amaranth preparations elicited significantly lower glycaemic responses compared to wheat- and rice-based products in non-insulin-dependent diabetic subjects.

The relatively lower GI of amaranth may be attributed to its higher protein content, appreciable dietary fiber, and complex carbohydrate matrix, which collectively slow gastric emptying and glucose absorption. These structural and compositional characteristics contribute to moderated insulin demand and improved glycaemic stability.

For individuals with diabetes or insulin resistance, inclusion of low-GI foods is associated with enhanced glycaemic control and reduced metabolic fluctuations. Thus, beyond its nutritional density, amaranth presents considerable potential as a functional dietary component in metabolic health management.

Bioactive Phytochemicals and Functional Properties

Beyond its macronutrient composition, *Amaranthus cruentus* contains a diverse range of bioactive phytochemicals that enhance its functional food value. The grain is reported to contain phenolic acids such as ferulic acid, *p*-coumaric acid, gallic acid, and caffeic acid, which exhibit strong free radical scavenging activity (Zhu, 2015). These compounds mitigate oxidative stress by neutralizing reactive oxygen species, thereby contributing to cellular protection and reduction of chronic disease risk.

Flavonoids including quercetin and rutin have also been identified in amaranth (Kumar et al. 2018). These bioactive molecules possess antioxidant, anti-inflammatory, and vasoprotective properties, supporting cardiovascular and metabolic health. In addition, amaranth contains saponins and bioactive lipids such as squalene, which have been associated with cholesterol-lowering effects through modulation of lipid metabolism and reduced intestinal cholesterol absorption (Mlakar et al. 2012).

Emerging evidence further suggests that peptide fractions derived from amaranth proteins demonstrate antioxidant and anti-inflammatory activity. Collectively, these phytochemical constituents significantly enhance the nutraceutical potential of amaranth beyond its basic nutritional composition.

Food Innovation and Culinary Applications

The functional versatility of *Amaranthus cruentus* was assessed through development of gluten-free bread, puri, and roti to evaluate its feasibility for regular dietary incorporation beyond fasting contexts.

Gluten-Free Bread Development

Bread was formulated using amaranth flour as the primary ingredient, combined with water, yeast, oil, salt, and corn starch as a structural support agent. In wheat-based systems (*Triticum aestivum*), gluten proteins form an elastic network that traps carbon dioxide during fermentation and provides structural integrity. In contrast, amaranith dough lacks gluten and relies on starch gelatinization and hydration properties for stability (Alvarez-Jubete et al. 2010). Corn starch enhanced gas retention and improved crumb softness. The final bread exhibited 36.07% moisture, producing a soft and palatable texture.

Roti and Puri Preparation

Flatbread products required optimized water incorporation and controlled manual shaping due to reduced extensibility. Despite lower elasticity than wheat dough, acceptable structural integrity and sensory quality were achieved.

Processing Considerations and Popularity Index.

Moderate water and oil absorption capacities supported moisture retention and mouthfeel. Consumer evaluation revealed 65% preference for bread, 20% for puri, and 15% for roti, indicating stronger acceptance of structured bakery applications.

Sustainability and Agricultural Relevance

Amaranthus cruentus offers notable agronomic advantages alongside its nutritional value. As a C4 crop, it exhibits enhanced water-use efficiency and tolerance to heat and drought stress, making it suitable for India’s rain-fed and semi-arid systems (Rastogi and Shukla, 2013). Its adaptability to sandy, loamy, and marginal soils allows cultivation in regions where conventional cereals may underperform.

In India, grain amaranth is cultivated in Uttarakhand, Himachal Pradesh, Rajasthan, Gujarat, Jharkhand, Odisha, Karnataka, and Tamil Nadu. Yield studies report productivity levels of approximately 1000-1500 kg per hectare under typical conditions (Kumar et al. 2018). Owing to relatively low irrigation and moderate nutrient requirements, amaranth cultivation may reduce input intensity compared to high-input cereal systems.

Its resilience and efficient resource utilization support climate-adaptive agriculture and align with national priorities for sustainable food security and diversified cropping systems.

Market Potential and Future Directions

The expanding global gluten-free market, driven by increased awareness of celiac disease and lifestyle-related disorders, presents significant opportunities for *Amaranthus cruentus*. Growing demand for plant-based, sustainable, and nutrient-dense foods further enhances its commercial relevance (Grand View Research). Owing to its high-quality protein, low glycaemic index, and bioactive phytochemicals, amaranth is well positioned within health-oriented product segments (Rastogi and Shukla, 2013; Alvarez-Jubete et al. 2010). However, research gaps remain. Long-term clinical evidence supporting its role in glycaemic control, lipid regulation, and anti-inflammatory effects is limited. Future research should prioritize controlled clinical trials and large-scale standardization studies to improve processing efficiency, shelf stability, and cost-effectiveness, thereby strengthening scientific validation and market integration.

Conclusion

Amaranthus cruentus emerges as a nutritionally superior pseudocereal, distinguished by high-quality protein, elevated lysine content, a favorable glycaemic response, and diverse bioactive compounds (Rastogi and Shukla, 2013; Alvarez-Jubete et al. 2010). The successful development and consumer acceptance of gluten-free products such as bread, roti, and puri highlight its functional adaptability in daily diets. Beyond its nutritional merits, its climate resilience, low agronomic input requirements, and suitability to Indian agro-ecological conditions underscore its role in sustainable food systems. Collectively, these attributes position amaranth not merely as a traditional fasting grain but as a strategic crop for health-focused and climate-resilient dietary patterns.

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Nano-Enabled Nutraceuticals: A Review

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Abstract

Nano-enabled nutraceuticals are foods or food products that combine functional foods, dietary supplements, and nanotechnology to produce therapeutic benefits. Traditional nutraceuticals can suffer from poor bioavailability, solubility, stability, and targeting properties. Nano-based delivery systems can enhance dissolution rates and allow for site-specific delivery, protection of bioactives, and controlled release of nutraceuticals to allow lower doses with higher therapeutic efficacy and lower toxicity. Safety concerns, long-term toxicity, regulatory issues, and consumer acceptance still need to be addressed. Additional studies are warranted to guarantee safety, scalability, and standardized regulations for widespread implementation into medicine and preventative nutrition.

Keywords: Nutraceuticals; Nanotechnology; Bioavailability.

Introduction

Bioactive substances obtained from food sources that offer health advantages beyond basic nourishment are known as nutraceuticals. Nutraceuticals are bioactive compounds derived from food sources that provide health benefits beyond basic nourishment. Probiotics, polyphenols, omega-3 fatty acids, vitamins, and carotenoids are common examples. Despite their potential, many nutraceutical compounds have significant practical application limitations because of their poor water solubility, instability in physiological environments, low bioavailability, and rapid deterioration during processing and storage. (Huang et al., 2010).

Nano-enabled nutraceuticals incorporate delivery systems at the nanoscale (generally <1000 nm) that enhance the functional properties of bioactive compounds. Nano-formulations exploit physicochemical advantages such as high surface area, tunable surface properties, and controlled release capabilities to address inherent limitations of conventional nutraceuticals (McClements, 2018). This review summarizes the principles of nano-delivery systems, advantages of nano-enabled nutraceuticals, major types of nanocarriers, application areas, safety considerations, regulatory aspects, and future directions.

Need for Nano-Enabled Nutraceuticals

Bioactive nutraceutical compounds with low solubility in aqueous media and low permeability across the GI tract are absorbed inefficiently and have low systemic availability. For instance, curcumin, an effective phenolic compound with potential antioxidant and anti-inflammatory effects, has very little oral bioavailability because of its quick metabolism and poor solubility. In a similar vein, heat, oxygen, and light cause fat-soluble vitamins and omega-3 fatty acids to get unstable (Salvia-Trujillo et al., 2017).

Nanoformulation strategies have been designed to address these limitations, improving solubilization, protecting labile compounds against degradation, and improving permeation and release. Furthermore, nanosystems can facilitate targeted delivery of therapeutic agents to specific tissues and cell surface receptors, potentially improving therapeutic effects and reducing unwanted effects

Types of Nano-Delivery Systems

Nutraceutical nano delivery systems can be broadly categorized into a number of groups with unique structural and functional attributes (McClements, 2018).

Nano-emulsions

Oil droplets scattered in water (oil/water nano-emulsions, O/W) or water droplets scattered in oil (water/oil nano-emulsions, W/O) with droplet sizes between 20 and 200 nano-meters make up nano-emulsions. The nano-emulsion system has a higher surface area that can be used to enhance the solubility of nutraceuticals.

Nanoliposomes

Nanoliposomes are spherical vesicles made up of one or more layers of phospholipid molecules. They can be used to encapsulate both hydrophobic and hydrophilic nutraceuticals.

Nanoparticles (SLNs)

SLNs have a solid lipid core and are stabilized by a surfactant. The solid core protects against chemical degradation and allows for controlled release.

Nanostructured Lipid Carriers (NLCs)

Solid and liquid lipids are combined to create NLCs, the second generation of lipid nanoparticles.

Polymeric Nanoparticles

Biodegradable polymers such as chitosan, alginate, and poly (lactic-co-glycolic acid) (PLGA) are used to create these nanoparticles. Polymeric nanocarriers can be used for stability and sustained release, and surface engineering can be used for targeting specific tissues.

Nanofibers

Nanofibers are formed mainly through electrospinning. They are used for controlled release and coatings of functional foodstuffs (Bhushani & Anandharamakrishnan, 2014).

Dendrimers

Dendrimers are highly branched, monodisperse macromolecules with multiple end groups, which can be used for carrying numerous bioactive molecules.

Figure 1 Types of Nanodelivery

Advantages of Nano-Enabled Nutraceuticals

Nano-enabled nutraceuticals offer multiple functional and biological advantages ((Garg et al., 2017; McClements, 2018):

Enhanced Solubility and Bioavailability: Many bioactives are poorly soluble in water, which limits absorption. Nanoformulations enhance dissolution rates due to increased surface area and reduced particle size, leading to higher bioavailability. For example, curcumin nanoemulsions have shown significantly higher absorption compared to conventional formulations.

Improved Stability and Shelf Life: Nanoencapsulation protects labile bioactives against environmental stressors such as heat, oxygen, and light. This improved stability extends shelf life and preserves functional properties during storage and processing

Controlled and Sustained Release: Nanosystems like polymeric nanoparticles and lipid carriers can be engineered to release compounds gradually over time, maintaining therapeutic concentrations and reducing dosing frequency.

Targeted Delivery: Surface functionalization enables targeting to specific tissues or cellular receptors, improving therapeutic outcomes and minimizing systemic side effects.

Reduced Dosage and Toxicity: Improved bioavailability means that lower doses may achieve the desired therapeutic effect, potentially reducing toxicity and side effects.

Improved Sensory Properties

Nanoencapsulation can mask unpleasant tastes or odors and improve texture, which enhances consumer acceptance in functional foods.

Applications in Functional Foods and Supplements

Nano-enabled nutraceuticals have been successfully incorporated into various products (Salvia-Trujillo et al., 2017).:

Functional Beverages: Omega-3 fatty acid, vitamin, and bioactive polyphenol nanoemulsions have been successfully added to functional drinks, improving their stability and transparency without sacrificing flavor

Dietary Supplements: Phytochemicals such as resveratrol, curcumin, and coenzyme Q10 have been found to be more effective when used as nano-enabled nutraceuticals for dietary supplements.

Fortified Foods: Nano-enabled nutraceuticals have been used for the fortification of foods with nutrients such as iron, vitamin D, and probiotics while ensuring the stability of the nutrients during processing.

Safety and Toxicological Considerations

Although there are advantages, there are also concerns regarding the safety of nano-enabled nutraceuticals. It has been observed that nanoparticles may behave in a different way compared to their bulk counterparts, and their small size may cause unknown effects in their interaction with biological systems. It is very important to carry out thorough safety tests, such as genotoxicity, cytotoxicity, and in vivo tests, before the nano-enabled nutraceuticals are marketed (Anselmo & Mitragotri, 2019)

Challenges and Limitations

Several challenges persist in the development of nano-enabled nutraceuticals:

Scale-Up and Manufacturing: Translating laboratory methods to large-scale production is complex, expensive, and requires stringent control over particle uniformity and stability (McClements, 2018).

Cost and Consumer Perception: High production costs and consumer concerns about "nano" technologies may limit market adoption.

Regulatory Barriers: Lack of standardized regulatory frameworks across countries creates uncertainty for manufacturers seeking global distribution.

Conclusion

Nano-enabled nutraceuticals represent a transformative advancement in the delivery and efficacy of bioactive compounds. By enhancing solubility, stability, bioavailability, and targeting, nanotechnology overcomes many limitations of traditional nutraceuticals. However, safety, regulatory harmonization, manufacturing scalability, and consumer acceptance remain critical challenges. Continued research, standardized evaluation methods, and robust regulatory frameworks are essential to fully realize the benefits of nano-enabled nutraceuticals in health and nutrition.

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Formulation and Quality Standardization of Functional Nutri Bars Incorporating Moringa Leaf and Pod Powder

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Abstract

The demand for convenient, nutritious, and health-promoting foods has significantly increased during past few years, leading improvement in functional snack products such as Nutri bars. These bars provide balanced nutrition in a compact and portable form. *Moringa oleifera*, often referred to as a “miracle tree,” achived considerable attention due to its outstanding nutritional composition with wide range of bioactive compounds. This chapter reviews the development and quality evaluation of functional Nutri bars enriched with *Moringa oleifera* leaf and pod powder. *Moringa* leaves and pods enriched with proteins, dietary fibre with vitamins, minerals,antioxidants, can used as suitable ingredients for food fortification. *Moringa*-enriched Nutri bars inhance potential health benefits like antioxidant activity which improved micronutrient intake which support in combating malnutrition. However, further research is needed to optimize formulations, evaluate nutrient bioavailability, and assess long-term storage stability. The development of moringa-based functional Nutri bars represents a promising strategy for producing innovative, health-oriented snack products.

Keywords: Nutri bars; *Moringa oleifera;* formulations; antioxidants; malnutrition.

Introduction

Functional foods have attracted significant scientific and commercial interest because they provide health benefits beyond basic nutrition. These foods help improve nutritional status, enhance physiological functions, and reduce the risk of chronic diseases. Rapid urbanization, lifestyle changes, elevated use of energy and nutrient rich foods have contributed to the growing prevalence of micronutrient deficiencies, obesity, diabetes, and cardiovascular diseases

(Pareek et al., 2023). As a result, there is increasing demand for foods that provide both convenience and health benefits.

Moringa oleifera is widely cultivated in tropical and subtropical regions and is known for its edible leaves, pods, seeds, and flowers. The plant having essential nutrients like proteins, vitamins, minerals, with antioxidants. *Moringa* leaves having hue potential of calcium, iron, and potassium with vitamins like A & C. whereas pods are rich in dietary fibre and bioactive compounds. Which enhance their nutritional quality and functional properties (Panova, 2025). This chapter reviews the development and quality assessment of functional Nutri bars enriched with moringa leaf and pod powder.

Functional Foods and Nutri Bar Concept

Functional foods having ability to provid additional health benefits further than basic nutrition. These foods may help improve digestion, enhance immunity, and reduce the risk of chronic diseases. Now a day consumers are increasingly interested in functional food products that are convenient and nutritionally superior (Abdelwanis, 2024).

Nutri bars represent one of the most widely accepted forms of functional snack products. They are small, shelf-stable bars that provide concentrated nutrients in a convenient format. They are consumed by different population groups including athletes, school children, and working professionals. Athletes often use them as quick sources of energy during physical activity, while busy individuals consume them as meal replacements or healthy snacks.

Recent trends in functional food development emphasize the use of natural and plant-based ingredients. The addition of *Moringa oleifera* powder to Nutri bars is an example of this approach, as it enhances protein content, micronutrient density, and antioxidant activity (Trigo et al., 2023).

Table 1 Control and experimental Nutri bar formulation.

Ingredient %	**Nutri bar (g)**	**Source**
Moringa pod powder	1	(Shareef et al., 2019)
Moringa leaves powder	1	(Mishra et al., n.d.)
Jaggery	27	(Bashir & Yousuf, 2022)
Wheat flour	10	(Kumar et al., 2018)
Groundnut	10	(Çiftçi & Suna, 2022)
Butter	5	(Nasir et al., 2015)
Cashew nut	3	(Chen et al., 2023)
Almonds	3	(Richardson et al., 2009)
Dates	40	(Nasir et al., 2015)

Nutritional and Functional Importance of *Moringa oleifera*

Moringa Leaves

Moringa leaves are considered one of the most nutrient-dense plant materials used in functional food formulations. They are rich in essential minerals mainly iron, calcium, potassium, magnesium, with phosphorus and B-complex vitamins.

Furthermore, Moringa leaves contain a variety of bioactive compounds like flavonoids, carotenoids, phenolic acids. They having strong antioxidant properties which help to protect the body from oxidative stress as will as inflammation (Islam et al., 2021).

Moringa Pods

Moringa pods exhibit antimicrobial, anti-inflammatory, and cholesterol-lowering properties.

Despite their nutritional value, moringa pods have received relatively less attention in food product development compared to moringa leaves. Incorporating moringa pod powder into Nutri bars could therefore enhance the nutritional diversity and functional value of the product (Ariani, 2023).

Role of Ingredients in Functional Nutri Bar Development

The development of functional Nutri bars requires careful selection of ingredients to achieve desirable nutritional, functional, and sensory properties.

- **Jaggery:** Jaggery is a traditional natural sweetener obtained from sugarcane juice. Unlike refined sugar, it retains minerals such as iron, calcium, and potassium. In Nutri bars, jaggery acts as both a sweetening agent and a natural binder that helps hold the ingredients together.

- **Dates:** Dates are commonly used in Nutri bars due to their natural sweetness and high carbohydrate content. They contain glucose and fructose, which provide quick energy. Dates also contribute dietary fibre, vitamins, and minerals, while helping maintain the soft texture of the bar.

- **Nuts:** Nuts such as almonds, peanuts, and cashews are important ingredients in Nutri bars because they provide protein, healthy fats, vitamins, and minerals. They also enhance the taste, texture, and caloric value of the product (Kumar, et al., 2024)

- **Cereals:** Cereals such as wheat or oats provide complex carbohydrates and structural stability to the bar. They help improve the texture and provide sustained energy.

Quality Evaluation of Functional Nutri Bars

- **Nutritional Quality**

The incorporation of moringa leaf and pod powder significantly enhances the nutritional composition of Nutri bars. The addition of moringa increases protein content, dietary fibre, and micronutrient levels, making the product more nutritionally balanced. (Ariani, 2023; Pareek et al., 2023).

- **Sensory Quality**

Consumer acceptance of Nutri bars largely depends on sensory attributes such as colour, flavour, texture, and overall taste. Studies suggest that adding moringa powder in moderate quantities improves nutritional value without negatively affecting sensory properties.

Functional and Health Benefits

Moringa-enriched Nutri bars provide several health benefits due to the bioactive compounds like flavonoids and phenolic acids. Compounds reveal antioxidant and anti-inflammatory effects which help to reduce the risk of chronic diseases.

Shelf Life

Nutri bars generally have low moisture content, which helps prevent microbial growth and improves shelf stability. Ingredients such as nuts, cereals, and dried fruits further contribute to the product's long shelf life (Jin et al., 2025).

Research Gap

Although *Moringa* leaf powder has been widely studied in functional food formulations, limited research has focused on the combined use of *Moringa* leaf and pod powder in Nutri bars. Further studies are needed to determine optimal formulations, evaluate nutrient bioavailability, and assess long-term storage stability (Pareek et al., 2023).

Conclusion

Moringa oleifera has significant potential functional ingredient for food fortification because of its high nutritional value with bioactive compounds. The incorporation of *Moringa* leaf and pod powder into Nutri bars can enhance their nutritional profile, antioxidant activity, and functional benefits. *Moringa*-based Nutri bars therefore represent a promising functional snack product that can help address micronutrient deficiencies and support overall health.

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Innovations in Food Quality

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Abstract

At initial people were brought their food by hunting but as a time passes it was shift into farming. It means our food were rapidly advancing from hunting to AI powered quality food. From ancient farming in Mesopotamia to futuristic lab-grown meat and AI-powered diet planning, nutrition innovations have evolved through: Survival needs, scientific discovery, industrial growth, digital transformation, sustainability goals. They mainly focus on enhancing the safety, shelf life and sensory attributes of food product through advanced technology, sustainable practices. Food innovation will play a critical role in addressing global challenges such as food security, sustainability, and health.

Keywords: Innovation; Nutrition; Food; Health

Introduction

At ancient time for food man was totally depends on hunting and gathering food as time passes it shifts to farming and it was the first major nutritional innovation. In that they were started crop cultivation, developed irrigation system and started animal domestication. As day passes their crop yield starting to increase to maintain food quality they started preservation with some traditional methods. Drying, salting, smoking, and fermentation helped early humans to store food.

- **Drying** is one of the oldest preservation methods. Food (fish, meat, fruits, grains) was dried in the sun or air. Removing moisture prevented bacteria and mold growth. Still used today for raisins, dried fish, and jerky.
- **Salting:** Salt draws out moisture and kills microorganisms. It is Commonly used for preserving fish and meat. Eg.: Salted fish and cured meat.
- **Smoking:** Food was hung over fire to dry and absorb smoke. Smoke contains chemicals that slow bacterial growth. Added flavor while preserving meat and fish.
- **Fermentation:** is a process natural bacteria convert sugars into acids or alcohol. The acid prevents harmful bacteria from growing. Used to make

foods like yogurt, cheese, pickles, and fermented grains. Improved digestion and nutritional value.

- **Pickling:** here Food stored in saltwater (brine) or vinegar. Acidic environment prevents spoilage. It is Common for vegetables and fruits.
- **Storage in Cool Places:** Underground cellars, caves, and clay pots were used. Helped keep food cool before refrigerators existed.

In the past, food preservation depended on natural elements sun, salt, smoke, and beneficial bacteria. These simple but effective methods laid the foundation for modern food storage technologies.

Agriculture advancement

Agricultural development began around 10,000 BCE during the Neolithic Revolution. Early innovations aim to improved food production, supported population growth, and led to the rise of civilizations.

- **Domestication of Plants and Animals**: The shift from hunting-gathering to farming began in regions such as the Fertile Crescent. Early domesticated crops included wheat and barley, while animals such as sheep, goats, and cattle were raised for food and labor it started to get nutritious food products.
- **Crop Rotation and Soil Management:** During the Middle Ages, especially in Europe, the three-field crop rotation system improved soil fertility and crop yield by alternating crops each season. Irrigation Systems Ancient civilizations like Mesopotamia and Egypt developed irrigation canals to control river water and supply crops during dry seasons. This significantly increased agricultural productivity.
- **Development of Agricultural Tools:** The invention of tools such as the wooden plough, sickles, and later iron ploughs improved soil preparation and harvesting efficiency.
- **Grain Storage and Preservation:** Granaries and clay storage systems protected harvested grains from pests and moisture, ensuring food supply during famines or winter months.
- Agricultural advancements in the past such as domestication, irrigation, improved tools, crop rotation, and storage systems laid the foundation for stable societies and economic development. These innovations were crucial in transforming human civilization from nomadic lifestyles to organized agricultural communities.

In 20th century people where identified different nutritional deficiency result into discovery of different vitamin and nutrients. Government was set certain Dietary Standards & Guidelines in that specifically Recommended Dietary Allowances (RDAs) established during WWII. Introduction of the Food Guide Pyramid (1992) were taken place. Expansion of public health campaigns about fats, sugar, and salt help to set nutritional goals. It laid the foundation for Functional foods, personalized nutrition, Modern dietary guidelines and Global food security strategies. It was major shift from preventing starvation and deficiency to optimizing health and preventing chronic disease. High-yielding crop varieties and advanced fertilizers developed in the 1960s exponentially increased food availability and security. The introduction of domestic refrigerators in 1913 revolutionized the safety of perishable goods like milk and meat, drastically reducing foodborne illnesses. The late 20th century introduced genetically modified organisms, engineered to resist pests and improve the nutritional profiles of staple crops.

Prospectus on food innovations shaping the future (2026–2040) it will mainly be covering technology, sustainability, health, and consumer trends.

One of the significant innovations that has occurred is the alternative proteins which include plant and lab-produced meat. Companies are already developing plant-based proteins while cultured meat is being grown with cellular agriculture to minimize the harm done to the world by livestock farming. These alternative proteins include plant-based meat, cultured meat, and insect-based proteins, developed to reduce environmental impact and meet increasing global protein demand. Another breakthrough is the 3D food printing technology which features meal customization regarding nutrient requirements. This technology is targeted to serve a customized nutrition approach.

One of the newest breakthroughs is precision fermentation, which allows companies to create dairy and protein-rich alternatives without relying on the traditional farming of animals. Climate volatility (heatwaves, drought, flooding, salinity, emerging pests) is reshaping global agriculture. Gene editing especially CRISPR-based tools enables precise, faster, and often regulation-lighter crop improvement compared to traditional GMOs. Draught tolerance, heat resistance, flood tolerance, salinity tolerance will be produced it will help to improve yield. Emerging alternative protein sources it will capture up to 15–25% of global protein market by 2040. Sustainable agriculture technologies are important to meet global food demand while minimizing environmental impact. One major method is Vertical Farming, which grows crops indoors using controlled environments. Personalized nutrition involves designing diets based on an individual's genetics, microbiome, lifestyle, and health conditions. The future of nutrition focuses on personalization, sustainability, and global health improvement. Advanced packaging technologies will help to extend shelf life and reduce food waste.

Food innovation will play a critical role in addressing global challenges such as food security, sustainability, and health. Emerging technologies like alternative proteins, personalized nutrition, and smart food systems are expected to transform the food industry in the coming decades.

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Nutritional Enhancement (Biofortification): Advances in Super-Crops, Pharma-Crops, and Reducing Anti-Nutrients

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Abstract

Biofortification has emerged as a key agricultural biotechnology strategy to combat global malnutrition by improving the nutritional quality of staple crops. This chapter reviews advances in nutritionally enhanced “super-crops,” development of pharma-crops, and reduction of anti-nutritional factors through gene silencing and related technologies. It integrates case studies, recent findings, and regulatory and ethical considerations, highlighting scientific innovations, practical challenges, and future prospects of biofortified crops as sustainable solutions to micronutrient deficiencies and food insecurity.

Keywords: Biofortification, Super-crops, Metabolic engineering, Pharma-crops, Essential nutrients.

Introduction

Despite progress in global food security, hidden hunger deficiency of essential vitamins and minerals still affects billions, especially in developing regions relying on nutrient-poor staple foods (Bouis and Saltzman, 2017). Conventional strategies such as dietary diversification, supplementation, and food fortification are often impractical in resource-limited settings. Biofortification, which enhances nutrient levels in crops through agronomic practices, conventional breeding, and biotechnology, has emerged as a cost-effective and sustainable solution to improve nutritional quality (Saltzman et al., 2013).

Modern crop biotechnology enables targeted enrichment of edible tissues with micronutrients such as provitamin A, iron, zinc, and essential amino acids through metabolic engineering. Plants are also being developed as production platforms for vaccines and pharmaceutical proteins, known as molecular farming or “pharma-crops.” Additionally, gene silencing technologies help reduce anti-nutritional factors, improving both safety and nutritional value.

These advances highlight biofortification's growing role in addressing malnutrition and enhancing global food systems.

Nutritionally Enhanced "Super-Crops"

The Rationale for Super-Crops

Micronutrient deficiencies impair immunity, productivity, and cognition, especially in children and pregnant women. Staple crops supply calories but lack provitamin A, iron, zinc, and essential amino acids (WHO, 2021; Bouis & Saltzman, 2017).

Metabolic Engineering for Nutrient Enrichment

Golden Rice: A Landmark in Vitamin A Biofortification

The development of Golden Rice marked a milestone in plant metabolic engineering. Genes from daffodil (Narcissus pseudonarcissus) and Pantoea ananatis enabled rice endosperm to accumulate β-carotene, a vitamin A precursor. This biofortified rice can supply up to half of children's daily vitamin A requirements, helping address deficiency (Paine et al., 2005; Tang et al., 2012).

Provitamin A Maize and Cassava

Other initiatives have been made to focus on maize and cassava besides rice. African countries have developed and launched provitamin A-biofortified maize varieties, which become a staple product with a better nutritional value (Pixley et al., 2013). In cassava, metabolic engineering has produced varieties that are richer in provitamin A and also those that have better shelf life (Welsch et al., 2010).

Biofortification for Zinc and Iron

Zinc and iron deficiencies cause anemia, poor growth, and infection susceptibility. Biofortification strategies include ferritin overexpression, enhanced metal transporters, and reduced phytate to improve mineral absorption (Trijatmiko et al., 2016; Bouis and Saltzman, 2017). Transgenic rice expressing soybean ferritin increased iron levels two- to threefold (Lucca et al., 2002).

Enhancement of Essential Amino Acids

Most cereals lack essential amino acids. Quality Protein Maize improves lysine and tryptophan; gains reported in rice (Prasanna et al., 2001; Ufaz & Galili, 2008).

Socioeconomic Impacts and Adoption

Over 40 countries have released and adopted biofortified crops with millions of households now enjoying enhanced nutrition (Saltzman et al., 2013). To achieve the success of such crops, not only scientific innovation, but also efficient delivery systems, uptake by farmers, and uptake by consumers, it is important that interdisciplinary collaboration should be present.

Pharma-Crops: Plants as Bioreactors

The Concept of Molecular Farming

Molecular farming utilizes plants' biosynthetic capacity to produce pharmaceuticals such as vaccines, antibodies, and therapeutic enzymes. Compared to conventional systems like mammalian cell culture, plant-based production is scalable, cost-effective, and carries lower risk of contamination by human pathogens (Stoger et al., 2014).

Production of Vaccines and Therapeutic Proteins

Plant-Derived Vaccines

Edible vaccines use genetically engineered plants to produce immunogenic proteins, offering a promising immunization strategy, especially in low-resource settings (Ma et al., 2005). Transgenic potatoes and bananas expressing antigens of Norwalk virus and Hepatitis B have shown potential in preclinical and early clinical studies (Tacket et al., 1998; Thanavala et al., 2005).

Monoclonal Antibodies and Biopharmaceuticals

Monoclonal antibodies and therapeutic proteins have been produced in plants, including those in the treatment of Ebola, rabies and cancer of different types (Zeitlin et al., 2011; Yang et al., 2008). Human serum albumin, which is an essential blood protein, has been obtained in rice cell cultures at commercial levels (He et al., 2011).

Industrial Enzymes

Transgenic crops can also be developed to manufacture industrial enzymes, including cellulases to generate biofuels, and phytases to be used in animal feed (Twyman et al., 2003). The environmental impact and cost of using plants are also less than using microbial fermentation.

Challenges and Regulatory Considerations

Pharma-crops offer promise but raise regulatory and biosafety concerns, including gene transfer, environmental risks, and product consistency. Responsible deployment requires containment strategies and strict regulatory frameworks (Ma et al., 2005).

Reducing Anti-Nutrients Through Gene Silencing

Anti-Nutritional Factors and Their Impact

Anti-nutrients are naturally occurring compounds that reduce the bioavailability of nutrients or pose health risks. Examples include:

- **Phytate:** Binds minerals like iron and zinc, reducing their absorption.

- **Cyanogenic Glycosides:** Release toxic hydrogen cyanide, especially in cassava.
- **Gossypol:** A toxic compound in cottonseed that restricts its use in animal and human diets.
- **Allergens:** Proteins in peanuts, soybeans, or wheat that can provoke severe allergic reactions.

RNA Interference (RNAi) and Gene Editing

Mechanism and Advantages

RNA interference (RNAi) is a gene-silencing methodology that uses the process of degrading certain messenger RNAs and thus causing the down-regulation of undesirable proteins or metabolites (Waterhouse et al., 2001). The CRISPR/Cas9 gene editing has also enlarged the repertoire of anti-nutrients reduction with a high level of accuracy (Zhang et al., 2018).

Case Studies

- RNAi and gene-editing approaches have improved crop safety and nutrition. In cassava, RNAi silencing of cyanogenic glycoside genes reduced cyanide content (Jorgensen et al., 2005).
- In cottonseed, targeted RNAi lowered gossypol in seeds, enabling safe food and feed use (Sunilkumar et al., 2006).
- In peanuts and wheat, RNAi and CRISPR/Cas9 reduced allergenic proteins, decreasing risks of severe allergic reactions (Dodo et al., 2008; Sánchez-León et al., 2018).

Broader Impacts

Lowering the quantity of anti-nutrients in foods does not only increase the nutritional quality of foods but also expands the application of agricultural by-products, improving food safety, and possibly eliminates the expensive food processing and food supplementation.

Conclusion

Metabolic engineering, molecular farming, and gene silencing in biofortification are transforming global nutrition and food safety. Nutrient-enhanced super-crops, pharma-crops, and anti-nutrient-reduced varieties offer sustainable solutions to malnutrition, disease prevention, and food security. Despite progress, realizing biofortification’s full potential requires greater research investment, clear regulatory frameworks, public engagement, and equitable access. Future food systems must move beyond calories to ensure improved health, safety, and resilience for populations worldwide.

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Role of Fungi in Modern Agricultural Biotechnology and Crop Improvement

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Abstract

Fungi are among the most versatile groups of organisms exploited in agricultural biotechnology. Their interactions with plants range from mutualistic symbiosis to antagonism toward pathogens and pests. Progress in genomics, metabolomics, molecular biology and fermentation technologies has broadened the use of fungi in enhancing crop. Helpful fungi improve nutrient absorption, promote plant growth, and protect crops from insect pests and diseases. This chapter offers a detailed overview of fungal biology relevant to biotechnology, major functional groups of agriculturally important fungi, mechanisms underlying their beneficial effects, genetic and molecular techniques employed for their enhancement and future opportunities in sustainable agriculture.

Keywords: Fungi; Biotechnology; enzymes; Mycorrhiza; *Trichoderma; Aspergillus niger*

Introduction

Traditionally, plant breeding and chemical inputs, such as fertilizers and pesticides are the foundation of crop improvement. However, due to environmental issues, soil degradation, and climate change there is growing need for sustainable alternatives. Fungi play indispensable roles in natural ecosystems as decomposers, symbionts, and biological control agents. Harnessing these capabilities through biotechnology has led to innovative solutions for improving crop productivity, resilience, and sustainability of crops. Fungi represent a varied category of eukaryotic, heterotrophic life forms classified under the Kingdom Fungi. Unlike plants, fungi do not contain chlorophyll and are unable to carry out photosynthesis. Instead, they derive nutrients by absorbing organic material from their surroundings. Fungi encompass, yeasts, rusts, mushrooms, molds and smuts.

Fungal Groups Important in Crop Improvement

Mycorrhizal Fungi

Mycorrhiza is a mutualistic association between fungal hyphae and plant roots that enhances water and nutrient uptake while fungi obtain carbohydrates. Mycorrhizal inoculants improve root growth, drought tolerance, and crop yield, while increasing absorption of phosphorus and micronutrients and reducing fertilizer dependence. Arbuscular mycorrhizal fungi act as biofertilizers by improving nutrient availability and soil processes (Zarafi & Dauda, 2019) and enhance water uptake during drought (Kothari et al., 1990). Species such as *Rhizophagus irregularis* improve phosphorus uptake, whereas ectomycorrhizae are mainly associated with forest trees.

Endophytic Fungi

Endophytic fungi are promising tools in crop biotechnology, living within plant tissues without causing disease while improving nutrient uptake, stress tolerance, and pathogen resistance. For example, *Piriformospora indica* enhances plant growth and tolerance to drought and salinity. These fungi are explored as natural growth promoters in sustainable agriculture, also improving tolerance to salinity, heavy metals, and pathogens.

Biocontrol Fungi

Fungi serve as biological control agents against plant pathogens and insect pests, reducing chemical fungicide use and supporting sustainable agriculture. Antagonistic fungi act through mycoparasitism, antibiotics, enzymes, and induced resistance. Species like *Trichoderma harzianum* control soil-borne pathogens, while *Trichoderma viride* suppresses damping-off and promotes growth. *Gliocladium virens* targets *Pythium* and *Rhizoctonia*. Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* control insect pests in integrated pest management.

Saprophytic Fungi and Enzyme Producers

Saprophytic fungi obtain nutrients from decomposing organic matter and play vital roles in agriculture by recycling nutrients and improving soil health. Species such as *Aspergillus niger*, *Penicillium chrysogenum*, *Trichoderma harzianum*, and *Rhizopus stolonifer* decompose organic residues, releasing nitrogen, phosphorus, and potassium. They enhance soil fertility, structure, and nutrient cycling. Some also suppress pathogens through competition and antifungal metabolites, produce growth hormones, improve root development, and increase nutrient uptake. Additionally, saprophytic fungi accelerate composting and convert agricultural waste into valuable biofertilizers, supporting sustainable farming.

Mechanisms of Fungal-Mediated Crop Improvement

Fungi significantly enhance crop yields by means of various biological and biochemical processes. Their interactions with plants range from beneficial symbiosis to protective antagonism. Through nutrient mobilization, disease suppression, stress tolerance enhancement, and production of growth-promoting substances, fungi contribute significantly to sustainable crop improvement.

Nutrient Mobilization

Enhanced nutrient solubilization is another key fungal mechanism. Fungi release organic acids and enzymes that convert insoluble minerals into plant-available forms. For example, *Aspergillus niger* produces organic acids that mobilize phosphorus. Enzymes such as cellulases, proteases, and phytases decompose organic matter, releasing nutrients, improving soil fertility, and supporting sustainable nutrient cycling in agricultural ecosystems.

Plant Growth Regulators Production

Fungi enhance crop growth by producing plant hormones such as auxins, gibberellins, and cytokinins, which promote root elongation, seed germination, and overall development. Endophytic fungi like *Piriformospora indica* colonize plant tissues without causing disease, improving biomass, nutrient uptake, and stress tolerance. These interactions increase plant vigor and productivity under both normal and adverse environmental conditions.

Induced Systemic Resistance (ISR)

Induced Systemic Resistance (ISR) is a vital mechanism in fungal biocontrol. Fungi such as Trichoderma harzianum suppress soil-borne pathogens through mycoparasitism, production of chitinases and glucanases, and antifungal metabolites. They also trigger ISR in plants, activating defense responses, reducing disease incidence, and improving overall crop health.

Abiotic Stress Tolerance

Fungi aid in crop enhancement by boosting resilience to abiotic stresses. Mycorrhizal and Endophytic fungi enhance plant tolerance to drought, salinity, heavy metals, and temperature fluctuations. They control osmotic equilibrium, enhance antioxidant function, and boost water absorption.These physiological adaptations assist plants in sustaining growth and productivity during stressful conditions.

Molecular and Genetic Approaches in Fungal Biotechnology

Fungi have become indispensable tools in modern agricultural biotechnology because of their ability to produce bioactive compounds, enzymes, and growth-promoting metabolites. Advances in molecular biology and genetics have allowed scientists to manipulate fungal species for enhanced crop improvement, disease control, and sustainable farming. Molecular and genetic approaches in fungal biotechnology encompass genome analysis, genetic engineering, metabolic pathway modification, and molecular breeding, all of which contribute to the optimization of fungal traits for agricultural applications.

Genomics and Transcriptomics

Genome sequencing and functional genomics reveal genes responsible for fungal biocontrol, enzyme production, secondary metabolites, and plant interactions. For example, studies on *Trichoderma harzianum* identified chitinase and glucanase genes, enabling selection of improved strains for pathogen suppression. Transcriptomics and proteomics further identify stress-responsive genes, supporting development of robust fungal strains for diverse agricultural applications.

Genetic Engineering of Fungi

Genetic engineering is vital in fungal biotechnology for enhancing beneficial traits through gene insertion, deletion, or overexpression. Genes for plant growth–promoting compounds and enzymes like cellulases and phytases can be amplified to improve nutrient availability. Chitinase genes from *Trichoderma* species have also been introduced into crops, conferring resistance to fungal pathogens and improving crop health and productivity.

Advantages of Fungal Biotechnology in Crop Improvement

Enhanced Nutrient Availability

Fungi, such as *mycorrhizal* species (e.g., *Glomus intraradices*), improve nutrient uptake in plants, especially phosphorus, nitrogen, and micronutrients. Their hyphal networks increase root surface area and solubilize otherwise unavailable minerals through enzymatic activity. This leads to healthier plant growth and higher yields without the use of excessive chemical fertilizers.

Natural Disease Management

Fungi such as *Trichoderma harzianum* and *Beauveria bassiana* function as biocontrol agents through the suppression of pathogens and pests found in soil. They generate antifungal compounds and break down pathogen cell walls,and stimulate systemic resistance in plants. This lessens crop losses while reducing the effects of artificial pesticides on the environment.

Eco-Friendly and Sustainable

Fungal biotechnology promotes environmentally sustainable farming. Unlike chemical inputs, fungal biofertilizers and biopesticides are biodegradable, non-toxic, and do not accumulate in soil or water. They help maintain soil biodiversity, improve soil structure, and support a long-term ecological balance.

Cost-Effectiveness

Utilizing fungi as biofertilizers or biocontrol agents decreases the reliance on costly chemical fertilizers. and agrochemicals. Fungal inoculants can be mass-produced using inexpensive substrates, making them economically viable for both small- and large-scale farmers.

Stress Tolerance in Plants

Endophytic and mycorrhizal fungi improve plant resilience to abiotic stressors like drought, salt concentration, and toxic metals. For instance, *Piriformospora indica* improves water uptake, regulates osmotic balance, and stimulates antioxidant activity. This increases crop resilience to challenging environmental conditions.

Improved Crop Quality and Yield

Fungal biotechnology not only increases the quantity of crop production but also improves quality. Plants associated with beneficial fungi often show enhanced nutrient content, improved root development, and stronger resistance to diseases. This contributes to a higher market value and food security.

Support for Modern Biotechnological Approaches

Fungi serve as model organisms in molecular biology and genetic engineering, providing tools for developing transgenic crops, producing industrial enzymes, and optimizing metabolite production. The integration of these techniques with modern biotechnology further enhances their role in crop improvement.

Conclusion

Fungi are powerful tools in agricultural biotechnology that offer sustainable solutions for crop improvement. Fungi contribute significantly to modern agriculture through nutrient mobilization, growth promotion, stress tolerance, and biological control. Ongoing studies in molecular biology, genomics, and industrial biotechnology will improve their effectiveness and dependability, establishing them as key components in future climate-resilient agriculture systems.

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A Comprehensive Review: Taxonomy and Biogeography of Wood- Rotting Polyporales

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Abstract

Polyporales, a diverse order of poroid macro-fungi within the class *Agaricomycetes* (*Basidiomycota*), comprises nearly 2,500 known species worldwide. These shelf-like wood-rotting fungi play a crucial role in forest ecosystems by decomposing lingo-cellulosic substrates, thereby facilitating carbon cycling and nutrient-turnover. Despite their ecological importance, global diversity and distribution patterns remain insufficiently-documented. This review compiles literature records and databases to synthesize bio-geographical distribution and taxonomic advances in Polyporales. Taxonomic approaches have evolved from reliance on gross morphology to incorporation of micro-morphological traits (hyphal system, sterile structures), rot types (white/brown), cytological studies, protein electrophoresis, and ITS rDNA sequencing. Recent phylogenetic analyses have provided significant insights into classification and evolutionary relationships. Beyond ecological functions, polypores exhibit antimicrobial, antioxidant, and enzymatic properties, underscoring their potential in pharmaceutical and industrial applications. This review highlights the dual significance of Polyporales as key agents of ecosystem sustainability and as promising resources for bioactive exploration.

Keywords: Polyporales, *Basidiomycota*, wood-rotting fungi, biogeography, taxonomy.

Introduction

Polyporales are a diverse order of wood-inhabiting macro-fungi under phylum Basidiomycota, comprising over 2,500 described species globally. They are known for their distinctive shelf-like fructifications with characteristic pore-bearing poroid or lamellate hymenium and therefore commonly referred to as "polypores”. The unique feature of these fungi is the presence of gymnocarpic unilateral hymenium.

Morphological & Anatomical Characteristics

Polyporales are diverse fungi ranging annual to perennial. The basidiocarp exhibit various forms like resupinate to pileate (sessile, sub-sessile or stipitate) and consists of cap crust, context tissue and tube layers. Abhymenial surface of pileus represent distinct colours which mostly remains unchanged during life span along with distinct key textures; hymenial surface poroid to daedaleoid. The pileus shows distinct margin and its development in pileate to resupinate ranging from fibrillose, concolorous and indeterminate manner. *Polyporales* produce sexual spores called **basidiospores** on microscopic structures called basidia located inside tubes, often characterized by varied shapes and structures.

Consistency/Hyphal System

The hyphal system and sterile ancillary structures like cystidia form the consistency of polypores. Corner (1932a, b, c) contributed this foundational concept and proposed 3 types of hyphal systems, namely

- Monomitic (generative hyphae)
- Dimitic (generative and skeletal/binding hyphae
- Trimitic (generative, skeletal and binding hyphae)

Biogeographical Distribution

Polyporales display remarkable global diversity, with over 2,500 species described to date. Their distribution is strongly influenced by host and climate: white-rot polypores typically colonize angiosperm wood, while brown-rot species favour conifers (Zhao et al., 2024; Xu et al., 2025). Richness is uneven worldwide, tropical and subtropical forests hosting greatest diversity due to stable climates, complex habitats, and high productivity. Boreal and arid regions support fewer species, though harbour unique taxa that serve as indicators of old-growth conditions (Nayka and Gautam, 2025).

Tropical America, particularly Amazon Basin and Central America, is major hotspot, followed by tropical Asia and Africa (Zhao et al., 2024). China (tropical to temperate zones) reports over 1,200 species, making it one of richest countries for polypore diversity (Xu et al., 2025). Molecular surveys further reveal “dark taxa,” genetic lineages yet to be formally described, underscoring the need for systematic surveys to capture true extent of *Polyporales* diversity (Runnel et al., 2021).

Taxonomical Insights

The taxonomy of *Polyporales* has evolved considerably since Micheli’s “*Nova Plantarum Genera”* (1729), which first described 14 pore-bearing species under genus *Polyporus*. Initially, these fungi were placed within family *Polyporaceae* under order *Aphyllophorales*, but later elevated to independent order *Polyporales* (Gäumann, 1926). Hawksworth et al. (1983) further supported this separation, rejecting *Aphyllophorales* as a valid grouping.

Advances in molecular phylogenetics reshaped fungal classification in the early 2000s. Kirk et al. (2001) divided *Basidiomycetes* into *Tremellomycetidae* and *Agaricomycetidae*, with poroid fungi distributed across *Boletales, Hymenochaetales, Polyporales,* and *Russulales*. Large collaborative projects such as AFTOL-I and II (2002–2011) deepened understanding of fungal evolution, leading to revisions by Blackwell, James, and Hibbett. Kirk et al. (2008) further refined *Basidiomycota* into three subphyla—*Pucciniomycotina, Ustilaginomycotina,* and *Agaricomycotina (3 classes)*, with poroid fungi spread across ten orders.

Molecular systematics revealed that "polypores" are not a single lineage but multiple evolutionary groups. Consequently, *Polyporales* is now narrowly defined as one of several *Agaricomycetes* orders containing poroid, wood-decaying fungi (Runnel et al., 2021) (Moura et al., 2020). Current revisions recognize 18–20 families. Recent work has added new families such as *Climacocystaceae* and *Gloeoporellaceae* (Liu et al., 2023; Nayka and Gautam, 2025).

Thus, taxonomy of *Polyporales* illustrates a shift from morphology-based classification to molecular phylogenetic, highlighting both complexity and dynamic nature of fungal systematics.

Ecological Importance

The ecological role of polypore within forest ecosystems are numerous, significantly wood degradation and engaging in complex interactions with other organisms, both symbiotically and as pathogens, contribute to the sustainability of forest ecosystems. These dual roles highlight complex dynamics within forest ecosystems, where polypore fungi can be both beneficial and detrimental to their host trees (Pawlowicz et al, 2024).

Economic Importance

- Polypore mushroom mycelia as an adjunct to COVID-19 vaccination (G. Saxe et al., 2026). They also showed antimicrobial, antiviral, cytotoxic, and antitumor effects (Zyawiony, 2004 and Kaur, 2023).
- Lignolytic enzymatic activities of *Polyporales* can be used in bio-bleaching and bio-pulping of paper and rayon industries (Goud et al, 2011 and Patil et al., 2024).
- Polypore genera *Coriolus, Trametes, Pyonoporus, Ganoderma* and *Formitella* have been used for mycelial mat formation as alternative sources of materials replacing fossil fuel-based materials (Bae et al., 2021).

Conclusion

The present review emphasizes that there is very rich unexplored biodiversity of polypore fungi, with only 2,500 species described across the world. The distribution patterns of *Polyporales* depend on type of forest, climatic conditions and presence of suitable host substratum. The advanced phylogenetic perceptions have made the successful taxonomic placement of *Polyporales* to avoid any consensus.

The polypore fungi play a crucial role in forest ecosystem. Therefore, further research and conservation management will ensure that these polypore fungi remain in their undisturbed place long into the heart of world's forest.

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Applied Perspectives on the Economic Significance and Biotechnological Potential of *Fomes fomentarius* (L.) Fr and *Flavodon flavus* (Klotzsch) Ryvarden

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Abstract

Wood-decay basidiomycetes play a significant ecological role in forest ecosystems in addition to offering a range of commercial applications. Among these, *Fomes fomentarius* (L.) Fr. and *Flavodon flavus* (Klotzsch) Ryvarden are two ecologically significant white-rot fungi with growing industrial, medicinal, and environmental significance. This chapter offers a comprehensive evaluation of their taxonomy, ecology, biochemical characteristics, economic significance, and prospects for applied biotechnology. In order to evaluate their commercial viability in frameworks for sustainable development, a critical analysis of current research trends, constraints, and opportunities is also presented.

Keywords: *Fomes fomentarius* (L.) Fr.; *Flavodon flavus* (Klotzsch) Ryvarden; Wood-decay basidiomycetes; White-rot fungi; Forest ecology; Industrial applications; Medicinal potential; Environmental biotechnology; Bioremediation; Sustainable development.

Introduction

White-rot fungi are specialised basidiomycetes that use extracellular oxidative enzyme systems to break down lignin, cellulose, and hemicellulose (Kirk and Farrell, 1987; Hatakka, 1994). These fungi are essential to the global carbon cycle because they are the main decomposers of woody biomass (Gilbertson and Ryvarden, 1986; Rayner and Boddy, 1988). White-rot fungi are distinguished from brown-rot and soft-rot fungi by their capacity to break down lignin, a complex aromatic polymer that is resistant to the majority of microorganisms (Kirk and Cullen, 1998; Martínez *et al*., 2005).

Among these, the ecological adaptability and enzymatic efficiency of *Fomes fomentarius* (L.) Fr and *Flavodon flavus* (Klotzsch) Ryvarden have drawn scientific interest (Ryvarden and Johansen, 1980; Gilbertson and Ryvarden, 1986). Modern research has repositioned these fungi as useful biological resources in pharmaceuticals, biomaterials, and environmental biotechnology, despite the fact that they were formerly mostly thought of as wood-decay organisms that caused timber deterioration (Grienke *et al*., 2014; Appels *et al*., 2019).

Taxonomy and Morphological Overview

Fomes fomentarius (L). Fr.

- Kingdom: Fungi
- Phylum: Basidiomycota
- Class: Agaricomycetes
- Order: Polyporales
- Family: Polyporaceae

The perennial bracket fungus *Fomes fomentarius* (L.) Fr is distinguished by a hard, woody basidiocarp that resembles a hoof. The surrounding tissue is corky and fibrous, and the pore surface is grey to brown In temperate climates, it frequently colonises beech (*Fagus* spp.), birch (*Betula* spp.), and other hardwoods (Bakshi, 1971; Ryvarden and Johansen, 1980).

Flavodon flavus (Klotzsch) Ryvarden

- Kingdom: Fungi
- Phylum: Basidiomycota
- Class: Agaricomycetes
- Order: Polyporales
- Family: Polyporaceae

Flavodon flavus (Klotzsch) Ryvarden often develops resupinate to effused-reflexed fruiting bodies that are yellowish to ochraceous and resemble crusts. In tropical and subtropical regions, it primarily develops on disintegrating hardwood substrates (Núñez and Ryvarden, 2001).

Ecological Role and Forest Economics

Wood Decay Mechanism

Both species are white-rot fungi capable of selective and simultaneous lignin degradation. They secrete oxidative enzymes including:

- Laccase
- Lignin peroxidase
- Manganese peroxidase

These enzymes break down lignin, allowing cellulose exposure and further decomposition.

Impact on Timber Industry

Wood colonization by *F. fomentarius* leads to internal decay, reducing mechanical strength and market value of timber (Schwarze *et al*., 2000).

Similarly, *F. flavus* contributes to deterioration of stored wood. Economic losses include:

- Reduced lumber grade
- Structural weakness in wooden constructions
- Increased forestry management costs

However, these fungi simultaneously enhance long-term soil fertility by recycling nutrients (Rayner and Boddy, 1988).

Historical and Ethnomycological Importance of *Fomes fomentarius (L.) Fr.*

One of the earliest documented uses of *F. fomentarius* is as tinder material. The processed inner tissue, known as **amadou**, was used for fire-starting. Archaeological findings confirm its presence in Neolithic contexts, including the belongings of Otzi the Iceman (Peintner *et al*., 1998).

Traditional uses include

- Fire ignition material
- Felt-like textile production
- Wound dressing (styptic properties)
- Fly-fishing absorbent pads

These uses supported small-scale traditional economies in Europe and Asia.

Medicinal and Pharmacological Potential

Bioactive Compounds in *Fomes fomentarius* (L.) Fr.

Research Indicates the Presence of

- β-glucans
- Phenolic acids
- Triterpenoids
- Sterols

These Compounds Exhibit

- Antioxidant activity
- Anti-inflammatory effects
- Antimicrobial properties
- Immunomodulatory potential

Wasser (2002) emphasized medicinal mushrooms as sources of bioactive polysaccharides with antitumor potential. However, most findings remain limited to laboratory-scale studies.

Bioactive Potential of *Flavodon flavus (Klotzsch) Ryvarden*

Though less explored medicinally, studies indicate antioxidant and antimicrobial potential due to secondary metabolites. Further phytochemical screening is required to fully characterize its pharmacological value.

Industrial Enzyme Production

Ligninolytic Enzymes

Both species produce industrially significant enzymes

Enzyme	**Industrial Application**
Laccase	Dye decolorization, biobleaching
Manganese peroxidase	Lignin degradation
Lignin peroxidase	Pollutant detoxification

(Hatakka, 1994)

Applications

- Paper and pulp biobleaching
- Textile dye degradation
- Effluent treatment
- Bioremediation of aromatic pollutants

White-rot fungi reduce chemical consumption in industrial processing, lowering environmental impact.

Biomaterials and Sustainable Innovations

The field of mycelium-based materials is expanding quickly. The mycelium of *F. fomentarius* has demonstrated potential for:

- Packaging that is biodegradable
- Panels for acoustic insulation
- Alternatives to leather
- Composites that are environmentally beneficial

These uses support the objectives of sustainable material development and the circular bioeconomy.

Environmental Biotechnology and Waste Valorization

Bioremediation

White-Rot Fungi Degrade

- Synthetic dyes
- Polycyclic aromatic hydrocarbons
- Phenolic effluents

Flavodon flavus (Klotzsch) Ryvarden shows promising dye decolorization ability in laboratory trials.

Biomass Pretreatment for Biofuel

Lignin degradation improves cellulose accessibility for bioethanol production. These fungi can be integrated into biomass conversion pipelines.

Comparative Economic Analysis

Parameter	***Fomes fomentarius***	***Flavodon flavus***
Timber Damage	Significant	Moderate
Historical Use	Extensive	Limited

Medicinal Value	High research interest	Emerging
Enzyme Production	Strong	Strong
Biomaterial Potential	High	Under exploration
Bioremediation	Moderate	High

Challenges and Limitations

- Limited large-scale cultivation protocols
- Variability in enzyme yield
- Lack of standardized pharmacological validation
- Commercial scalability constraints
- Need for genetic and strain improvement

Industrial adaptation requires improved fermentation systems and bioprocess optimization.

Future Research Directions

1. Genome sequencing and metabolic pathway analysis
2. Genetic engineering for enhanced enzyme production
3. Clinical validation of medicinal properties
4. Integration into circular bioeconomy models
5. Commercial pilot-scale enzyme production

Interdisciplinary collaboration among mycologists, biotechnologists, and material scientists is crucial.

Conclusion

Fomes fomentarius and *Flavodon flavus* (Klotzsch) Ryvarden exemplify the dual ecological and economic roles of white-rot fungi. While historically recognized as wood-decay organisms causing timber losses, modern research has revealed their substantial value in medicine, biomaterials, enzyme biotechnology, and environmental sustainability. Harnessing their full economic potential requires technological innovation, industrial-scale validation, and sustainable commercialization strategies.

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Relationship between Plants and Endophytic Fungi and Its Efficacy on Bioactive compounds: A Review

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Abstract

Endophytic fungi are microorganisms that inhabit internal plant tissues without causing harm and establish mutualistic relationships with their hosts. Bioactive compounds derived from endophytic fungi exhibit antimicrobial, anticancer, antiviral, and antioxidant properties. The interaction between endophytes and host plants influences metabolite production, which is regulated by genetic and environmental factors. Numerous metabolites such as alkaloids, terpenoids, phenolics, steroids, and quinones have been reported from endophytes. These compounds demonstrate effectiveness against drug-resistant pathogens and various human diseases. Increasing antimicrobial resistance and emerging viral infections underscore the need for alternative bioactive compounds, positioning endophytic fungi as valuable sources for future pharmaceutical development.

Keywords**:** Endophytic Fungi, Endospheric Tissue, Secondary Metabolites

Introduction:

Endophytic fungi can help the host plants to protect themselves from environmental factors and pathogens and also in the development. (Wani 2015, Alvin et al. 2014). The endophytic fungi get the protection and nutrients from host plant and provides them with nutrients in return; endophytic fungi produce secondary metabolites which helps the plant to defend themselves against pathogens. (Tan & Zou 2001) The interaction between plant and endophyte is genetically regulated by both organisms and further modulated by environmental conditions. (Moricca and Ragazzi, 2008. B**ioactive metabolites** which are having **cytotoxic, fungicidal and bactericidal activities** are produced by Endophytes isolated from medicinal plants. (Wang et al. 2007) This review focusses on relationship between endophytic fungi and host as well as its efficacy on bioactive compounds.

Antimicrobial compounds

The emergence of pathogens that are resistant to currently active drugs has become a difficult challenge for medical field, mainly due to the ability of microorganisms to acquire new mechanisms that enable them to resist antimicrobial agents. (Elbasuney 2021, Costelloe C,2010) Effective antimicrobial drugs should be discovered to overcome this issue. Various biological activities like antimicrobial, anticancer, antioxidant and antiviral are exhibited in bioactive compounds obtained from endophytic fungi. Endophytes are known to produce A large number of bioactive secondary metabolites which are having antimicrobial activity against various pathogens are produced by endophytic fungi.

Anticancer Compounds

Due to the broad distribution and noticeable diversity in living organisms, endophytic fungi are considered one of the most promising sources of natural antitumor drugs in recent days. (Omeje et al. 2017) Taxol and its derivatives were the first anticancer drug reported from endophytes. Strobel et al.in 1996 stated that several genera of endophytic fungi, including *Alternaria*, *Fusarium*, *Monochaetia*, *Pestalotia*, *Pestalotiopsis*, *Pithomyces*, and *Taxomyces* produced the anticancer drug taxol. researchers have focused on controlling and optimizing culture conditions since the discovery of taxol from a fungal endophyte. This approach has led to the production of several novel and bioactive compounds. (Strobel et al. 2004) Current research focuses on developing innovative anticancer compounds and therapies that specifically target cancer cells while minimizing adverse side effects. (Zaden *et al.*, 2020).

Antiviral Compound

The global challenge of drug resistance has developed the urgent need to the development of new and innovative antiviral compounds. Only limited compounds from endophytes have been reported as antiviral agents. The Antiviral compounds discovery is more challenging because of the lack of antiviral screening systems. (Song, 2005) The ongoing emergence of new virus serotypes, marked by high mutation rates and low replication fidelity, complicates efforts to control these pathogens. Furthermore, the increasing resistance of human pathogens to existing antibiotics emphasizes the urgent need for alternative therapeutic strategies. (Ayobami Elias Ajadi2024) A major challenge in developing effective antiviral drugs is the lack, inadequacy, or unsuitability of robust antiviral screening methods.

Conclusions

Many bioactive compounds are produced from endophytic Fungi. Secondary metabolites isolated from Endophytic fungi will be a preliminary source for pharmaceutical drugs. Increasing challenges of drug-resistant microorganisms and the development of new diseases have heightened the necessity of novel bioactive compounds. New therapeutic agents can be emerged from the isolation and screening of fungi from various habitats because of their ability to produce diverse bioactive metabolites. Endophytic fungi can lead the way for the development of new drugs and possess significant potential as sources of antimicrobials.

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Future Perspectives in Agricultural and Plant Innovation

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Abstract

Agriculture in the twenty-first century faces mounting challenges from climate change, population growth, land degradation, and resource scarcity, necessitating sustainable and resilient production systems. Advances in plant science, biotechnology, and digital technologies are transforming agricultural practices. Genome editing, molecular breeding, and speed breeding accelerate the development of climate-resilient crops with improved productivity and nutritional value. Precision agriculture, supported by sensors, artificial intelligence, and remote sensing, enhances resource-use efficiency and enables data-driven decision-making. Sustainable soil health is promoted through microbiome engineering, regenerative agriculture, and conservation practices. Controlled environment agriculture, including vertical farming and hydroponics, offers efficient food production in urban settings. Synthetic biology and plant-based biomanufacturing provide eco-friendly materials and pharmaceutical applications. Integration of genomics, big data, and nanotechnology further improves crop management and sustainability. Climate-smart agriculture, combined with ethical governance and socio-economic inclusivity, ensures equitable adoption of innovations. Together, these interdisciplinary approaches provide transformative pathways toward sustainable agriculture, environmental conservation, and global food security.

Keywords: Climate-resilient crops; Precision agriculture; Sustainable intensification; Plant biotechnology; Climate-smart agriculture

Introduction

Agriculture has always been the foundation of human civilization, yet in the twenty-first century it faces unprecedented challenges. Rapid population growth, projected to exceed 9 billion by 2050, increasing urbanization, climate variability, land degradation, freshwater scarcity, and biodiversity loss collectively threaten global food security. At the same time, agriculture must reduce its environmental footprint while ensuring equitable access to nutritious food. The need for sustainable intensification producing more from less while conserving natural resources has become central to global policy and scientific discourse.

The transformation of agriculture is increasingly driven by scientific and technological innovations in plant biology, biotechnology, digital systems, and ecological management. From genome editing tools such as CRISPR-Cas9 to satellite-guided precision agriculture supported by agencies like National Aeronautics and Space Administration and European Space Agency, the agricultural landscape is evolving rapidly. Furthermore, global policy guidance from institutions such as Food and Agriculture Organization and World Health Organization continues to shape sustainable practices worldwide.

This chapter explores emerging technologies, scientific breakthroughs, and socio-economic strategies that define the future of agricultural and plant innovation. It emphasizes interdisciplinary integration, sustainability, and resilience as the pillars of future agricultural systems.

Climate-Resilient Crop Improvement

Genome Editing and Molecular Breeding

Climate change is intensifying abiotic stresses such as drought, salinity, flooding, and heat stress. Traditional breeding, though effective, is time-consuming and limited by genetic variability within cultivated species. Genome editing technologies provide unprecedented precision in modifying plant genomes to introduce beneficial traits.

The CRISPR-based systems allow targeted gene knockouts, insertions, and base editing, facilitating rapid development of climate-resilient crops. For example, editing genes associated with stomatal density can enhance water-use efficiency, while manipulation of heat-shock protein genes can improve thermotolerance. Unlike conventional transgenic approaches, genome editing may avoid foreign DNA integration, potentially reducing regulatory barriers.

Molecular breeding is further enhanced by marker-assisted selection (MAS) and genomic selection (GS). These approaches integrate genotypic data with phenotypic performance, accelerating breeding cycles and improving accuracy.

Speed Breeding and Rapid Generation Advancement

Speed breeding uses extended photoperiods and optimized environmental conditions to shorten plant life cycles. Crops that normally produce one generation per year can produce up to four or six generations under controlled conditions. Coupled with genomic tools, speed breeding significantly accelerates cultivar development.

Future applications include stacking multiple stress-tolerance traits, enhancing micronutrient content (biofortification), and improving disease resistance to emerging pathogens.

Precision Agriculture and Smart Farming Systems

Sensor Technologies and Remote Sensing

Precision agriculture relies on real-time data acquisition. Soil moisture sensors, nutrient probes, canopy temperature sensors, and hyperspectral imaging systems enable site-specific management. Remote sensing through satellite imagery supports crop monitoring at regional and global scales.

Data obtained from space agencies like NASA and ESA include vegetation indices such as NDVI (Normalized Difference Vegetation Index), which are used to evaluate plant health and detect stress conditions. These datasets play an important role in forecasting crop yields and developing early warning systems for drought and pest infestations.

Artificial Intelligence and Decision Support Systems

Artificial Intelligence (AI) and Machine Learning (ML) algorithms analyze large datasets generated from farms. These tools predict disease outbreaks, optimize irrigation schedules, and recommend fertilizer doses based on soil nutrient status.

AI-powered robotics are being developed for automated weeding, harvesting, and phenotyping. Autonomous tractors equipped with GPS guidance systems reduce fuel consumption and improve precision.

Future developments will integrate blockchain for supply chain transparency, ensuring traceability from farm to consumer.

Sustainable Soil Health and Nutrient Management

Microbiome Engineering

Soil health is central to sustainable agriculture. Advances in metagenomics reveal complex interactions between plants and soil microbiota. Plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi, and nitrogen-fixing bacteria enhance nutrient uptake and stress tolerance.

Microbiome engineering aims to design synthetic microbial consortia tailored to specific crops and environmental conditions. This approach can reduce chemical fertilizer dependency and restore degraded soils.

Regenerative and Conservation Agriculture

Regenerative agriculture emphasizes soil carbon sequestration, biodiversity conservation, and ecosystem restoration. Practices include:

- Cover cropping
- Reduced or zero tillage
- Crop rotation

- Agroforestry
- Organic amendments

These practices improve soil structure, water retention, and microbial diversity while mitigating greenhouse gas emissions.

Carbon credit programs may incentivize farmers to adopt regenerative methods, linking agriculture to climate mitigation strategies.

Controlled Environment Agriculture (CEA)

Vertical Farming

Vertical farming utilizes stacked cultivation systems under controlled lighting and climate conditions. LED technology enables optimized light spectra for photosynthesis. Hydroponic nutrient delivery reduces water consumption by up to 90% compared to conventional agriculture.

Urban vertical farms contribute to food security, reduce transportation emissions, and provide fresh produce in metropolitan areas.

Hydroponics, Aeroponics, and Aquaponics

Soilless systems enhance nutrient efficiency and minimize disease risk. Aeroponics delivers nutrients via mist, promoting rapid root growth. Aquaponics integrates fish culture with plant production, creating a closed-loop ecosystem.

Future research focuses on cost reduction, automation, and renewable energy integration to improve scalability.

Synthetic Biology and Plant-Based Biomanufacturing

Synthetic biology redesigns plant metabolic pathways to produce high-value compounds such as pharmaceuticals, biofuels, and industrial enzymes. Plants can be engineered to synthesize biodegradable plastics and therapeutic proteins. Plant molecular farming uses crops as bio factories for vaccines and antibodies. This approach offers scalable and cost-effective production systems compared to traditional fermentation methods. Metabolic pathway engineering may also improve nutritional quality by increasing vitamins, antioxidants, and essential amino acids.

Digital Genomics and Big Data Integration

The integration of genomics, transcriptomics, proteomics, and metabolomics provides comprehensive insights into plant physiology. High-throughput phenotyping platforms collect data on growth rate, stress responses, and yield components.

Cloud-based bioinformatics platforms enable global collaboration. Big data analytics support:

- Gene discovery
- Trait mapping
- Predictive modelling
- Climate adaptability forecasting

Future agricultural research will increasingly rely on open-access databases and collaborative networks.

Nanotechnology in Agriculture

Nanotechnology applications include nano-fertilizers, nano-pesticides, and nano sensors. These materials enhance nutrient delivery efficiency and reduce environmental contamination. Controlled-release nano-formulations ensure gradual nutrient availability, minimizing leaching losses. Nano sensors detect pathogens and nutrient deficiencies at early stages.

However, environmental safety assessments are crucial to evaluate long-term ecological impacts.

Urban Agriculture and Smart Cities

Urban agriculture is expanding due to population concentration in cities. Rooftop gardens, community farming, and smart greenhouses enhance local food production. Smart city initiatives integrate agriculture into infrastructure planning. IoT-enabled greenhouses regulate temperature, humidity, and nutrient supply automatically. Policy incentives and educational programs will support urban food systems in the future.

Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture integrates productivity, adaptation, and mitigation. CSA practices include:

- Drought-tolerant crop varieties
- Efficient irrigation (drip systems)
- Integrated pest management
- Diversified cropping systems

CSA aligns agricultural development with climate adaptation goals and sustainable development frameworks.

Ethical, Regulatory, and Socioeconomic Dimensions

Technological innovation must be supported by robust regulatory frameworks. Public concerns about genetically modified organisms (GMOs) require transparent communication and risk assessment. Global guidelines from FAO and WHO provide biosafety standards. Intellectual property rights must balance innovation incentives with farmer accessibility. Bridging the digital divide is critical to ensure smallholder farmers benefit from technological advancements.

Challenges and Opportunities

Key Challenges

- Climate unpredictability
- Resource depletion
- High cost of advanced technologies
- Knowledge gaps in developing regions

- Policy and regulatory inconsistencies

Emerging Opportunities

- Public–private partnerships
- International research collaborations
- Sustainable finance models
- Youth engagement in Agri-entrepreneurship
- Integration of renewable energy with agriculture

Future Outlook

The future of agriculture lies in interdisciplinary convergence. Biotechnology, artificial intelligence, ecological management, and policy reform must operate synergistically. Sustainable intensification will depend on adaptive research systems, farmer participation, and evidence-based policymaking.

Resilient agricultural systems must prioritize biodiversity conservation, soil health restoration, and equitable technology distribution. With continued innovation and collaboration, agriculture can meet global food demands while preserving environmental integrity.

Conclusion

Agricultural and plant innovation is entering a transformative era. Genome editing, digital farming, microbiome engineering, nanotechnology, and controlled environment systems are reshaping crop production. Climate resilience, sustainability, and social inclusivity will guide future advancements. The success of future agriculture will depend not only on technological breakthroughs but also on ethical governance, farmer education, and global cooperation. By integrating science, sustainability, and social responsibility, agriculture can secure food systems for generations to come.

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Plant Science Frontiers: Advancing Sustainability Through Botanical Innovation

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Abstract

Plant science plays a key role in solving global challenges like food security, climate change, environmental degradation, and human health. Modern innovations combine technologies such as artificial intelligence, biotechnology, and genomics to improve crop productivity, conserve biodiversity, and develop sustainable solutions. Tools like biofortification, genome editing, and phytoremediation help create nutrient-rich crops and clean polluted environments. Overall, these advancements support sustainable development and enhance resilience to environmental challenges.

Keywords: Botanical innovation; Digital agriculture; Phytoremediation; Climate-resilient crops

Introduction

Humankind faces major challenges in food, health, energy, and the environment, intensified by climate change. Plants play a vital role as they support ecosystems and provide essential resources. Achieving sustainable development, as outlined in the UN Sustainable Development Goals (SDGs), requires balancing environmental protection, economic growth, and social well-being.

Advances in genome sequencing, biotechnology, and ecology have made plant science a multidisciplinary field. Modern botanical innovations include digital agriculture, gene editing, plant–microbe engineering, conservation genomics, and plant-based bioeconomy development.

This chapter highlights how these innovations contribute to sustainability at both local and global levels.

Digital Botany

- **AI-Based Disease Detection:** AI enhances early disease detection and crop monitoring, improving yield and reducing losses.

- **Remote Sensing and Drones:** Drones with advanced sensors capture high-resolution images to detect crop stress, pests, and diseases.
- **IoT and Smart Irrigation:** Soil sensors and automated systems optimize water use, improve efficiency, and reduce wastage.
- **Conservation Genomics:** Genetic diversity is essential for crop improvement and developing resilient cultivars.
- **DNA Barcoding and Species Monitoring:** Molecular tools help identify species and prevent illegal trade of endangered plants.
- **In Situ Conservation:** Protecting natural habitats maintains ecosystem balance and improves conservation outcomes.
- **Seed Banks and Cryopreservation:** Seed banks preserve plant genetic diversity and protect species from environmental threats.

Synthetic Biology

- *Bioplastics:* Plant-based biodegradable materials reduce pollution.
- *Pharmaceuticals:* Plants act as biofactories for vaccines and therapeutic proteins.

Plant Biotechnology for Sustainable Agriculture: Integrates IT and biotechnology to develop eco-friendly and efficient farming solutions.

Biofortification: Improves nutritional quality of crops to address micronutrient deficiencies.

Genome Editing (CRISPR): Enables precise genetic improvements for stress tolerance, yield, and disease resistance.

Marker-Assisted and Genomic Selection: Speeds up breeding and helps develop climate-resilient crops with greater accuracy.

Phytoremediation

Environmental deterioration remains the most significant challenge affecting present and upcoming generations. Resources of nature such as soil, wood, and water are deteriorating in many parts of the world, and more species are facing extinction than ever before (Nguyen *et al*., 2023). Phytoremediation is a relatively affordable and ecofriendly technology that uses plants to stabilize, soak up, reduce toxic load, or neutralize substances released into surrounding by numerous sources (Kafle *et al*., 2022). Phytoremediation can be done by: Phytostabilization, Rhizofiltration, Phytoextraction, Phytodegradation, etc.

Phytostabilization

It is a commonly used to remediate metal contaminated soils. The adsorption of metal and deposition in the rhizosphere, fusion with root exudates, and storage in root vacuoles are the primary processes that limit their transfer to shoots. It reduces heavy metal contamination in the food system and water while enhancing condition of the soil (Kuang et al.,2025).

Rhizofiltration

Rhizobacteria produce metabolites that directly take part in heavy metal bioremediation Furthermore, the tolerance to metallic compounds of the Plant Growth Producing Bacteria and the host plant is an essential determinant in remediation of soil (Mukherjee *et al*., 2024).

Phytoextraction

Appropriate removal of metallic substances from contaminated soils will be vital for reducing harmful effects on plant growth and avoiding human health concerns from consumption damaged crops. Plants accumulate heavy metals in their tissues during phytoextraction, and harvesting the above-ground biomass removes the pollution from the location (Eben *et al*., 2024).

Climate-Resilient Crops

Considering the increasing impact of climate change on world food supply, breeding climate-resilient crops capable of adjusting with abiotic stress is an essential task in agriculture. Salinity, drought, high temperatures, and nutrient deficiencies are among abiotic stresses that have a deleterious effect on production of crop. Thus, technologies such as marker assisted breeding, mutant breeding, genetic engineering, and genome editing provide a brighter future for generating climate-resilient crops (Cabusora, 2024).

Conclusion

Plant science frontiers are one of the most potential paths to sustainable development. Botanical innovation offers sustainable and nature-based solutions to critical global concerns, including genome editing and climate-resilient crops, phytoremediation, digital agriculture, conservation genomics, and synthetic biology. Plants remain critical to environmental stability as humanity battles with climate change, resource depletion, and biodiversity loss. Botanical innovation is crucial for ensuring a sustainable and environmentally stable future.

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Advances in Plant Growth Technologies for Sustainable Food Production in Space

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Abstract

This chapter discusses recent advances in plant growth technologies for sustainable food production in space. Plants are important for long-time space missions as they create oxygen, recycle carbon dioxide, and supply astronauts with fresh and nutritious food. However, the space environment presents several challenges, including microgravity, cosmic radiation, and limited atmospheric control, which can influence plant growth and development. To overcome these challenges, scientists have developed specialized plant growth systems such as hydroponics, aeroponics, and solid substrate cultivation, along with controlled growth chambers and LED lighting. Understanding the molecular and physiological responses of plants in space contributes to the development of efficient bioregenerative support systems.

***Keywords*:** Astronauts agriculture, microgravity, plant growth, hydroponics, aeroponics, LED lighting, controlled environment, bioregenerative life support, sustainable food production, space missions.

Introduction

Space biology is an interdisciplinary field that examines how living organisms behave and adapt in the extreme conditions of outer space. Unlike Earth environment, the space is characterized by microgravity, intense cosmic ray, limited atmospheric control, confined living systems etc. These factors create unique challenges for biological processes, including growth, reproduction, metabolism, and survival. Among all biological systems studied in space, plants occupy a central role because they can support human life through production recycling and provision of fresh food.

Plant growth systems beyond Earth are designed to enable plants to grow efficiently in environments where gravity is minimal, radiation levels are high, and natural soil may not be available. Research in this field contributes not only to space exploration but also to innovations in sustainable agriculture on Earth.

Controlled environment agriculture, hydroponics, and vertical farming technologies have benefited significantly from space plant research.

Space environment and its impact on Plant Growth

Microgravity

One of the most significant differences between Earth and space is the absence of normal gravitational forces. This directional growth helps plants anchor themselves in soil and orient their leaves toward sunlight.

In microgravity conditions, this natural orientation mechanism is disrupted. Plants must rely on other environmental cues, such as light direction (phototropism) and moisture gradients, to determine growth patterns. As a result, plant structures may develop differently.

Space field

Another major challenge is exposure to cosmic and magnetic field, organisms encounter high-energy particles. These forms of radiation can damage cellular structures and genetic material.

Radiation exposure can cause DNA mutations, disrupt photosynthesis, and affect plant reproduction. If radiation damage accumulates over multiple generations, it could lead to reduced plant productivity or genetic instability.

However, some plants demonstrate remarkable resilience to radiation stress. Research has shown that plants can activate repair mechanisms that correct DNA damage and maintain cellular function. Such knowledge may help in selecting or engineering crops suitable for cultivation on the Moon or Mars.

Atmospheric and Environmental Constraints

Plants in spacecraft or extraterrestrial habitats grow in tightly controlled environments. Unlike natural ecosystems on Earth, these environments must be carefully engineered to maintain suitable conditions for plant growth.

One major challenge is limited air circulation. Without gravity-driven convection currents, air movement becomes slower, which can affect gas exchange around leaves and roots. This may influence photosynthesis and transpiration processes.

Carbon dioxide levels in spacecraft can also be higher than on Earth. While plants require carbon dioxide for photosynthesis, excessively high concentrations may disrupt normal.

Plant Growth Systems Used in Space

To overcome the challenges of growing plants in space, scientists have developed several specialized plant growth systems.

Hydroponic Systems

Hydroponic systems are helpful for water use. Water will be continuously recycled within the system, making it ideal for space missions where resources are limited.

Aeroponic Systems

Aeroponics is another promising technology for space agriculture. In this system, plant roots are suspended in air rather than immersed in water or soil. A fine mist of nutrient solution is periodically sprayed onto the roots to provide moisture and essential minerals.

Solid Substrate Systems

In some experiments, plants are grown in inert solid materials such as clay pellets, rock wool, or synthetic soil analogs. These substrates provide mechanical support for plant roots while allowing water and nutrients to circulate through the system.

Plant Growth Chambers and Space Experiments

To conduct plant research in space, specialized growth chambers have been developed. These chambers provide carefully controlled environmental conditions necessary for plant development.

Modern plant growth units include LED lighting systems that deliver specific wavelengths of light optimized for photosynthesis. Automated watering systems regulate the supply of water and nutrients to plant roots. Environmental sensors continuously monitor temperature, humidity, carbon dioxide concentration, and oxygen levels.

Molecular and Physiological Responses of Plants in Space

Gene Expression and Signal Transduction

Plants exposed to spaceflight conditions undergo significant molecular changes. Studies using transcriptomics and proteomics have shown that many genes related to stress response, metabolism, and cell wall formation become activated in microgravity environments.

Signal transduction pathways help plants detect environmental changes and adjust their physiological responses accordingly. Hormones such as auxins, gibberellins, and cytokinins play important roles in regulating plant growth and development under space conditions.

Photosynthesis and Metabolism

Photosynthesis remains the fundamental process that enables plants to support life in space habitats. Artificial lighting systems using LEDs allow scientists to optimize light quality and intensity to maximize photosynthetic productivity. Carefully controlled environmental conditions ensure that plants maintain stable metabolic activity even in microgravity environments.

Role of Space-Grown Plants in Bio regenerative Life Support Systems

These systems plants play a central role in maintaining environmental balance. Plants produce oxygen for human respiration and also generate food for astronauts. Microorganisms associated with plant roots further contribute to nutrient cycling and waste decomposition.

Conclusion

Plant growth beyond Earth is essential for future space missions and human survival in space. Scientists have shown that plants can successfully grow in controlled environments using hydroponic, aeroponic, and other advanced systems. These methods help provide food, oxygen, and psychological support to astronauts during long missions. As technology improves, plant-based life support systems will play a key role in establishing sustainable human settlements in space while also inspiring better agricultural practices on Earth.

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Role of Nanomaterials in Sustainable Agriculture

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Abstract

Sustainable agriculture seeks to enhance crop productivity while reducing environmental impacts and conserving natural resources. Conventional farming practices often rely heavily on chemical fertilizers and pesticides, leading to soil degradation, water pollution, and greenhouse gas emissions. Nanotechnology offers innovative solutions to these challenges through the use of nanomaterials with unique properties such as high surface area, enhanced reactivity, and controlled release. Nanofertilizers improve nutrient use efficiency and reduce losses, while nanopesticides provide targeted pest control with minimal effects on non-target organisms. Nanosensors enable real-time monitoring of soil health, moisture, and crop stress, supporting precision farming. Nano-carriers facilitate efficient delivery of genetic materials and bioactive compounds, enhancing plant growth and stress tolerance. Additionally, nanomaterials improve soil structure, water retention, and disease management. However, concerns regarding toxicity, cost, regulatory frameworks, and long-term environmental effects remain. With proper risk assessment and guidelines, nanomaterials have strong potential to promote sustainable, efficient, and environmentally friendly agricultural systems.

Keywords: Nanofertilizers; Nanopesticides; Nanosensors; Sustainable Agriculture

Introduction

Achieving high agricultural output while minimizing negative effects on the environment, cutting back on chemical inputs, and conserving natural resources is the goal of sustainable agriculture. Excessive fertilizer and pesticide use is a major component of traditional agricultural methods, which frequently result in soil deterioration, water contamination, and greenhouse gas emissions. The creation and use of materials at the nanometer scale (1–100 nm) is known as nanotechnology, and it provides revolutionary capabilities to improve agricultural sustainability. High surface area-to-volume ratios, adjustable reactivity, and controlled distribution capabilities are just a few of the special physicochemical qualities of nanomaterials that can help solve important problems in contemporary farming.

Types of Nanomaterials Used in Agriculture

Agricultural nanomaterials span multiple classes based on composition and function:

Nanofertilizers

Nano-fertilizers are advanced fertilizers developed using nanotechnology, in which essential plant nutrients are supplied in the form of nano-sized particles (1–100 nm). Because of their extremely small size and large surface area, nano-fertilizers are more efficient than conventional fertilizers. They provide nutrients to plants in a controlled and targeted manner, reducing losses due to leaching, volatilization, and fixation in soil.

Nano-fertilizers enhance plant growth, photosynthesis, enzyme activity, and overall crop productivity. They are especially useful for correcting micronutrient deficiencies such as zinc, iron, and copper. In addition, they help in reducing the quantity of chemical fertilizers required, thereby supporting sustainable and eco-friendly agriculture.

Example:Nano urea is a widely used nano-fertilizer in which nitrogen is supplied in nano form through foliar spray.

Nanopesticides

Nano-pesticides are pesticides formulated using nanotechnology, where active ingredients are nano-sized or encapsulated in nanomaterials for targeted delivery, improving efficacy and reducing harm to non-target organisms. They minimize losses from volatilization, photodegradation, and runoff, thereby lowering environmental pollution and supporting sustainable pest management. Nano-formulations also enhance botanical and biodegradable pesticides; for example, nano-encapsulated neem (azadirachtin) effectively controls insect pests (Kah & Hofmann, 2014; Nuruzzaman et al., 2016).

Nanosensors and Nanobiosensors

Nano-sensors are advanced devices built from nanoscale materials such as nanoparticles, carbon nanotubes, nanowires, and quantum dots. Their small size (1–100 nm) and high surface area provide exceptional sensitivity to detect minor physical, chemical, and biological changes. In agriculture, nano-sensors support precision farming by monitoring soil moisture, nutrients, pH, temperature, and early pest or pathogen presence. Real-time data enables efficient use of water, fertilizers, and pesticides, reducing waste and pollution. They also detect plant stress from drought, salinity, or nutrient deficiency, improving yield and quality. Additionally, nano-sensors assist in environmental monitoring and food safety by identifying pollutants and contaminants. Carbon nanotube-based nano-sensors, for example, can detect soil nitrogen levels.

Nano-carriers for Genetic and Bioactive Delivery

Nano-carriers are nanoscale delivery systems used to transport genetic materials (DNA, RNA) and bioactive compounds such as drugs, proteins, enzymes, and plant growth regulators to specific targets. Made from nanoparticles, liposomes, polymeric particles, dendrimers, or nanocapsules (1–100 nm), they cross biological barriers and ensure precise delivery. Nano-carriers protect molecules from degradation and enable controlled, sustained release, improving efficiency while reducing toxicity. In agriculture and biotechnology, they support gene delivery in plants, targeted application of pesticides and fertilizers, and enhancement of stress tolerance and disease resistance. They also improve bioavailability, lowering required doses and environmental impact. For example, chitosan-based nanoparticles are commonly used for DNA delivery in plants.

Mechanisms of Action in Plants and Soils

Enhanced Nutrient Delivery and Uptake

Nanofertilizers and nanoencapsulated nutrients can penetrate plant roots or leaf tissues more effectively due to their small particle size and high surface reactivity. This enhances nutrient absorption, reduces leaching, and allows for more efficient use of essential elements like nitrogen, phosphorus, and micronutrients.

Controlled Release and Targeted Pest Management

Mesoporous nanomaterials such as mesoporous silica nanoparticles or metal–organic frameworks can encapsulate pesticides and release them slowly based on environmental triggers. This mechanism improves pesticide stability, prolongs effectiveness, and reduces application frequency.

Soil Structure and Water Retention

Certain nanomaterials like nano-clays and zeolite composites improve soil physical properties by reducing bulk density and increasing porosity, which enhances water retention and nutrient availability. This supports drought resilience and reduces irrigation needs.

Stress Mitigation and Plant Growth Regulation

Nanomaterials can interact with plant cellular pathways, triggering antioxidant responses and stress resilience. Nano-enabled seed treatments (seed priming) have been shown to enhance germination and tolerance to salinity or drought conditions.

Applications of Nanomaterials in Sustainable Agriculture

- **Nano-Fertilizers:** Improve nutrient efficiency via controlled release, reducing losses and pollution.
- **Nano-Pesticides:** Provide targeted delivery, lowering dosage and harm to non-target organisms.
- **Nano-Sensors:** Enable real-time monitoring of soil, nutrients, and pests.
- **Nano-Carriers:** Deliver genes and bioactive compounds efficiently.
- **Soil Health:** Enhance structure, water retention, and microbial activity.
- **Disease Management:** Increase fungicide and biocontrol effectiveness.
- **Stress Tolerance:** Help plants withstand drought, salinity, and heat.
- **Post-Harvest:** Nano-coatings extend shelf life.
- **Water Management:** Improve irrigation efficiency.
- **Environmental Protection:** Reduce runoff and support sustainable agriculture.

Challenges and Safety Considerations

- Environmental impact: Long-term effects on soil and ecosystems remain unclear.
- Toxicity risk: Misuse may harm plants, animals, and humans.
- Regulatory gaps: Limited guidelines hinder safe agricultural use.
- High cost: Expensive production restricts small-farmer adoption.
- Limited field studies: Insufficient long-term trials reduce confidence.
- Instability: Nanomaterials may aggregate in soil.
- Uncertain fate: Soil–plant accumulation not fully understood.
- Low awareness: Public acceptance remains limited.
- Technical skills: Application requires expertise.
- Overuse risks: Improper use may increase pollution.

Conclusion

Nanomaterials represent a powerful tool in the transition toward sustainable agriculture. Their ability to enhance resource use efficiency, improve crop resilience, reduce environmental pollution, and integrate with precision farming technologies presents significant opportunities. However, realizing these benefits requires careful evaluation of environmental impacts, regulatory support, and accessible technologies that serve farmers across diverse socio-economic contexts.

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Science and Technology in Support of Sustainable Development

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Abstract

Sustainable development has emerged as a core guiding principle for global advancement in the twenty-first century. It seeks to fulfil the requirements of the current generation while safeguarding the capacity of future generations to meet their own requirements. This idea gained worldwide acceptance following the 1987 Brundtland Report published by the World Commission on Environment and Development. In 2015, the United Nations General Assembly formally adopted the Sustainable Development Goals (SDGs), establishing a comprehensive global roadmap for achieving sustainability by 2030. Science and technology play pivotal roles in realizing these objectives by providing knowledge, innovations, and actionable solutions to environmental, economic, and social issues. Scientific advancements have enabled balanced progress, from clean energy and eco-friendly farming to biotechnology and digital governance. Nevertheless, lasting sustainability demands ethical commitment, equitable growth, and robust international collaboration among countries and institutions. This study explores how science and technology contribute to environmental conservation, economic resilience, and social welfare, and examines the associated challenges and future pathways for sustainability.

Keywords: Sustainable; Environment; Development; Farming

Introduction

Sustainable development refers to progress that satisfies the needs of the present generation without undermining the prospects of future generations. The concept was formally introduced in the 1987 Brundtland Report and was later reinforced by the adoption of Sustainable Development Goals in 2015. These goals offer a universal framework for building a more equitable and ecologically secure global society.

In the contemporary era, science and technology are indispensable for addressing pressing global issues, such as climate change, food insecurity, water shortages, energy deficits, pollution, and loss of biodiversity. Scientific inquiry provides the necessary evidence and insights, and technology converts this understanding into practical applications. Without continuous research and technological breakthroughs, maintaining harmony between development and environmental preservation is challenging. Integrating scientific knowledge with sustainable practices is vital for achieving enduring growth and ecological balance.

Understanding Sustainability

Sustainable development rests on three closely interconnected pillars: environmental, economic, and social sustainability. Environmental sustainability involves the protection of natural resources, safeguarding of ecosystems, and preservation of ecological equilibrium. It encompasses measures for pollution prevention, biodiversity conservation, and the prudent utilization of renewable resources.

Economic sustainability aims to achieve steady economic expansion without depleting natural capital. It encourages innovation, job creation, and efficient resource utilization to ensure the long-term prosperity. Social sustainability focuses on fairness, universal access to quality education and healthcare, poverty alleviation, and enhancing living conditions.

These three dimensions are deeply interrelated. Genuine sustainability can only be realized when environmental protection, economic advancement, and social equity are pursued simultaneously.

Contribution of Science to Sustainability

Science forms the bedrock of understanding environmental processes and resolving societal challenges. Systematic research and innovation facilitate evidence-based policy-making and sustainable planning.

Environmental Protection and Monitoring

Scientific investigations enhance our understanding of climate change, biodiversity, and pollution. Tools such as remote sensing and Geographic Information Systems (GIS) enable effective monitoring of environmental shifts and prudent management of natural assets.

Scientific evaluations assist decision-makers in formulating strategies to curb greenhouse gas emissions and conserve ecosystems. Environmental monitoring networks assess air and water quality, monitor forest cover loss, and forecast the occurrence of natural disasters. Reliable scientific information is crucial for effective environmental governance in China.

Sustainable Agriculture

Farming is fundamental to ensuring food security and economic stability in the country. Advances in science have boosted agricultural output while minimizing environmental damage. High-yielding and drought-resistant crop varieties have enhanced the food production. Crops that are genetically modified to resist pests rely less on chemical pesticides. Organic cultivation methods improve soil health and limit the risk of contamination. Precision agriculture employs sensors and data analytics to optimize water and fertilizer application.

Water Resource Management

Water scarcity is a major global concern that affects all countries. Scientific and technological solutions promote the efficient utilization of water resources. Techniques such as rainwater harvesting enable the collection and storage of rainwater for future use. Wastewater treatment technologies facilitate the recycling and reuse of wastewater. Desalination plants convert seawater into fresh water in arid regions. Drip irrigation systems significantly reduce water loss and improve farming efficiency.

Importance of Technology in Sustainability

While science creates knowledge, technology translates this knowledge into tangible real-world solutions. Technological advancements have facilitated the widespread adoption of sustainable practices.

Renewable Energy Innovations

Clean energy sources help decrease reliance on fossil fuels and reduce greenhouse gas emissions. Solar, wind, hydropower, and biomass technologies offer environmentally sound options for electricity production. Shifting towards renewable energy is vital for mitigating climate change and guaranteeing long-term energy availability. Strengthening renewable energy infrastructure promotes sustainable economic and environmental growth.

Environment-Friendly Technology

Green technologies are designed to reduce their negative impact on the environment. Energy-efficient devices reduce the power consumption. Sustainable construction practices utilize eco-friendly materials and promote energy conservation.

Electric vehicles help curb atmospheric pollution and decrease dependence on conventional fuels. Advanced recycling technologies convert discarded materials into valuable resources, thereby advancing the circular economy and reducing landfill burden.

Biotechnology and Nanotechnology

Biotechnology and nanotechnology offer cutting-edge solutions to environmental challenges. Bioremediation employs microbes to decontaminate polluted soil and water. Biofertilizers naturally enhance soil fertility without the use of harmful chemicals.

Nanotechnology supports the development of highly effective water purification systems and precise environmental sensing. These approaches improve performance while causing minimal ecosystem damage.

Information and Communication Technology (ICT)

ICT contributes to sustainable development by enabling smart cities, digital administration and improved public service delivery. Digital platforms expand access to education and healthcare, particularly in remote areas. Online learning tools broaden educational opportunities, and telemedicine enhances medical services in remote regions. Digital analysis of climate information aids in forecasting weather events and improving disaster preparedness and responses. Overall, ICT enhances transparency, operational efficiency, and sustainability across multiple sectors.

Sustainability Goals (SDGs)

The 17 Sustainable Development Goals tackle major global issues, including poverty, hunger, education, gender equality, access to clean water, affordable and clean energy, decent work and economic growth, sustainable cities, responsible consumption and production, climate action, life on land, peace, and international partnerships.

These goals form a unified framework that links environmental protection, economic progress, and social priorities. Their successful implementation requires coordinated efforts from governments, businesses, academic institutions, and local communities worldwide.

Conclusion

Science provides the critical understanding needed to comprehend environmental and societal issues, and technology delivers practical tools to resolve them. Collectively, these factors contribute to minimizing environmental harm, reinforcing economic stability, and advancing social equity.

However, sustainable development requires more than just scientific and technological progress. Ethical accountability, inclusive decision-making, and meaningful public engagement are equally important issues. By combining scientific creativity, technological solutions, and well-designed policies, we can build a resilient and thriving future for all generations.

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Bioplastics and the Future of Green Technology

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Abstract

The invention of plastics revolutionized modern society by providing lightweight, durable, and cost-effective materials for diverse applications. However, the persistence of conventional petroleum-based plastics has resulted in severe environmental challenges, including long-term waste accumulation, ecosystem disruption, microplastic contamination, and increased greenhouse gas emissions. In response, bioplastics have emerged as a promising alternative designed to reduce dependence on fossil resources and mitigate ecological impact. Bioplastics are defined as materials that are bio-based, biodegradable, or both, and include a wide range of polymers derived from renewable resources such as starch, cellulose, vegetable oils, and microorganisms. Their development integrates polymer chemistry, biotechnology, and environmental engineering. Common types include polylactic acid (PLA), polyhydroxyalkanoates (PHA), starch-based plastics, and bio-polyethylene. While bioplastics offer advantages such as reduced carbon footprint, renewable feedstocks, and potential compostability, their sustainability depends on life-cycle considerations including agricultural inputs, energy consumption, and waste management infrastructure. Challenges such as higher production costs, limited composting facilities, competition with food resources, and performance limitations must also be addressed. Despite these constraints, bioplastics align with circular economy principles and represent a significant step toward sustainable material innovation. Ongoing research in green chemistry and synthetic biology is expected to enhance their functionality and environmental benefits, positioning bioplastics as an important component of future sustainable development strategies.

Keywords: Bioplastics; Biodegradable polymers; Renewable resources; Circular economy; Sustainable materials

Introduction

The invention of plastic in the early twentieth century marked a turning point in human civilization. Lightweight, durable, moldable, and inexpensive, plastics transformed industries ranging from healthcare and transportation to electronics and food packaging. Materials such as polyethylene, polypropylene, and polystyrene became symbols of modern convenience and economic growth. However, this remarkable innovation has also produced one of the most pressing environmental crises of our time. Conventional plastics derived primarily from fossil fuels, are resistant to natural degradation and can persist in the environment for hundreds of years. As a result, billions of tons of plastic waste have accumulated in landfills, rivers, and oceans, disrupting ecosystems, harming wildlife, and entering the human food chain in the form of micro plastics. The environmental cost of plastic pollution extends beyond visible waste. The extraction and processing of petroleum for plastic production contribute significantly to greenhouse gas emissions and climate change. The linear model of "produce, use, and dispose" has proven unsustainable in a world facing resource depletion and environmental degradation. As global plastic production continues to rise, the urgent need for alternative materials that balance functionality with environmental responsibility has become increasingly clear. In response to this challenge, scientists, engineers, and environmental innovators have turned their attention to bioplastics materials designed to reduce dependence on fossil resources and minimize ecological impact. Bioplastics represent a convergence of material science, biotechnology, chemistry, and environmental engineering. Unlike conventional plastics, many bioplastics are derived from renewable biological resources such as corn starch, sugarcane, cellulose, vegetable oils, or even microorganisms. Some are engineered to biodegrade under specific conditions, offering a potential solution to long-term waste accumulation. The concept of bio-based materials is rooted in nature itself. Long before synthetic polymers were invented, natural polymers such as cellulose, starch, and proteins served as structural materials in plants and animals. Modern bioplastics draw inspiration from these natural systems, applying advanced scientific techniques such as fermentation, polymerization, and genetic engineering to create materials with desired properties. This approach reflects a broader shift toward a circular economy an economic model that emphasizes renewable inputs, waste reduction, recycling, and environmental regeneration. However, bioplastics are not a simple or universal solution. The term encompasses a wide range of materials with different characteristics, benefits, and limitations. Some bioplastics are biodegradable but derived from fossil fuels; others are bio-based yet non-biodegradable. Their environmental impact depends on factors such as raw material sourcing, agricultural practices, energy consumption, waste management systems, and composting infrastructure. Therefore, understanding bioplastics requires not only scientific knowledge but also awareness of environmental policy, economic feasibility, and sustainable development principles. Today, as nations strive to meet climate goals and reduce plastic pollution, bioplastics stand at the forefront of sustainable innovation. Governments are encouraging research, industries are investing in green materials, and consumers are demanding environmentally friendly products. Advances in biotechnology are enabling the production of plastics from algae, agricultural residues, and even food waste, reducing competition with food crops. Continuous research aims to improve strength, heat resistance, affordability, and large-scale manufacturing capabilities. Bioplastics symbolize more than just a new material they represent a shift in human thinking. They reflect the recognition that technological progress must align with environmental stewardship. By integrating renewable resources, scientific innovation, and responsible consumption, bioplastics offer a pathway toward a greener and more sustainable future. This chapter explores the science, development, applications, challenges, and future potential of bioplastics, highlighting their role as one of the most significant innovations in modern material science

Bioplastics: Bioplastics are often presented as a simple solution to plastic pollution, but in reality, they represent a complex and evolving field of material science. To truly understand bioplastics, it is essential to explore their definitions, classifications, chemical structure, production methods, environmental impact, and practical limitations.

The term **bioplastics** refers to plastic materials that are either:

- **Bio-Based:** derived partially or entirely from renewable biological resources,

- **Biodegradable:** capable of being broken down by microorganisms into natural substances, Or both.

A common misunderstanding is that all bioplastics are biodegradable. This is not true. Some bioplastics are made from renewable plant sources but behave exactly like conventional plastics in terms of durability and resistance to degradation. Therefore, bioplastics can be divided into three main categories:

Table 1: Categories of Bioplastics

Category	Bio-based	Biodegradable
Type 1	Yes	Yes
Type 2	Yes	No
Type 3	No	Yes

Understanding this distinction is critical when evaluating their environmental benefits.

The Science behind Bioplastics

Polymer Chemistry: All plastics, whether conventional or bio-based, are made of polymers long chains of repeating molecular units called monomers. The properties of plastic depend on the type of monomer used, length of polymer chains, bonding structure and the degree of crystallinity. In bioplastics, the monomers are often derived from biological processes. For example:

- Sugars from plants are fermented into lactic acid.
- Lactic acid molecules are polymerized to form polylactic acid (PLA).

This process combines biology and chemistry, making bioplastics a product of interdisciplinary science.

Raw Materials Used in Bioplastics: Bioplastics are commonly produced from renewable resources such as:

- Corn starch
- Sugarcane
- Cassava
- Potato starch
- Cellulose
- Vegetable oils
- Agricultural waste
- Microorganisms (bacteria)

Advanced research is now exploring non-food biomass sources such as algae and industrial waste gases to reduce competition with food production.

Types of Bioplastics

1. Polylactic Acid (PLA)

- Derived from fermented plant sugars.
- Transparent and rigid.
- Used in food packaging and 3D printing.
- Requires industrial composting for degradation.

2. Polyhydroxyalkanoates (PHA)

- Produced naturally by bacteria as energy storage molecules.
- Fully biodegradable in soil and marine environments.
- Suitable for medical and packaging applications.

3. Starch-Based Plastics

- Made by blending starch with biodegradable polymers.
- Used in compostable bags and disposable items.

4. Bio-Polyethylene (Bio-PE)

- Made from sugarcane ethanol.
- Chemically identical to petroleum-based polyethylene.
- Not biodegradable but reduces fossil fuel dependency.

Biodegradability: Biodegradability depends on environmental conditions such as:

- Temperature
- Moisture
- Oxygen availability
- Presence of microorganisms

Some bioplastics degrade only in industrial composting facilities where temperatures reach 50–60°C. In natural environments like oceans or landfills, degradation may occur much more slowly.

Biodegradation typically produces:

- Carbon dioxide
- Water
- Biomass
- Methane (in anaerobic conditions)

Understanding these conditions is important because improper disposal can reduce environmental benefits.

Environmental Impact

Carbon Cycle Advantage

Plants absorb carbon dioxide during photosynthesis. When bio-based plastics are produced from plants, part of that carbon is stored temporarily in the material. This can lower the overall carbon footprint compared to fossil-based plastics.

Reduced Fossil Fuel Dependence

Bioplastics decrease reliance on non-renewable petroleum resources, contributing to energy security and sustainability.

Waste Reduction Potential

Compostable bioplastics may reduce long-term waste accumulation if proper waste management systems are available.

However, environmental impact assessments must consider:

- Land use changes
- Fertilizer and pesticide use
- Water consumption
- Energy used during production

Sustainability depends on the entire life cycle of the material.

Advantages of Bioplastics

- Renewable raw materials
- Lower greenhouse gas emissions (in many cases)
- Potential compostability
- Reduced environmental persistence
- Support for circular economy models

Challenges and Limitations

Despite their promise, bioplastics face several challenges:

- **Economic Barriers:** Production costs are generally higher than traditional plastics.
- **Infrastructure Limitations:** Composting and recycling systems for bioplastics are not widely available in many regions.
- **Agricultural Concerns:** Large-scale production may compete with food crops or contribute to deforestation.

- **Performance Limitations:** Some bioplastics have lower heat resistance or mechanical strength compared to petroleum-based plastics.

Bioplastics and the Circular Economy

Bioplastics align with the concept of a **circular economy**, which emphasizes:

- Designing products for reuse and recycling
- Using renewable inputs
- Minimizing waste
- Returning materials safely to nature

By integrating biological cycles with industrial processes, bioplastics aim to reduce environmental harm while maintaining modern material performance.

Future Directions in Bioplastics

Scientific innovation is focusing on:

- Producing bioplastics from algae and food waste
- Improving durability and thermal resistance
- Enhancing home-compostable materials
- Reducing manufacturing costs
- Developing advanced recycling technologies

Emerging fields such as synthetic biology and green chemistry are expected to play a major role in advancing bioplastic technology.

Conclusion

Understanding bioplastics requires more than knowing they are “eco-friendly plastics.” They are sophisticated materials created through the integration of biology, chemistry, engineering, and environmental science. While they are not a perfect solution to plastic pollution, they represent a significant step toward sustainable material innovation.

As research continues, bioplastics have the potential to transform industries and support a greener, more responsible future.

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Study of Cancer Epidemiology

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Abstract

Cancer is a multifactorial disease characterized by uncontrolled cell proliferation and the ability of abnormal cells to invade and metastasize to distant organs. Cancer arises due to genetic mutations such as proto-oncogenes, tumour suppressor genes, and DNA repair genes, leading to dysregulated cell growth. Tumours may be benign or malignant, with malignant tumours possessing invasive and metastatic potential. Various types of cancer such as carcinoma, sarcoma, myeloma, lymphoma, and mixed forms are discussed along with their tissue origins. Modern therapeutic approaches include chemotherapy, gene therapy, stem cell therapy, nanomedicine, natural antioxidants, extracellular vesicle-based therapy, and supportive non-pharmacological interventions.

Keywords**:** Cancer; Carcinogenesis; Cancer therapy.

Introduction

Cancer is the greatest common diseases that cause death. The analysis and handling of cancer stay to progress despite the ongoing challenge of finding a treatment thanks to advances in science and technology, as well as growing awareness and understanding. (Machathoibi Takhellambam Chanu 2024). Abnormal cell growing that can penetrate and eventually spread to other sections of the body is called cancer. Hippocrates (460–370 BC), a Greek physician, coined the term "cancer." Hippocrates believed that the human body had 4 fluids: blood, phlegm, yellow bile, and black bile. An individual was deemed well if their bodily fluids were in equilibrium. A higher level of black bile was thought to be the cause of cancer. Among the many hypotheses put out by numerous doctors are the theories of humour, lymph, the blastema, chronic irritation, trauma, and infectious diseases. (Howell, 2016).

Another name for tumours is "NEOPLASM." (Sinha, 2018). Prostate, liver, esophageal, and lung cancers are the most common among men in low-income countries, while breast, cervical, ovarian, and esophageal cancers are the more general among women. (Bordoloi *et al,* 2026)

A disease called as cancer arises when some body cells multiply out of controls and spread to other bodily organs. The humanoid body is composed of trillion of cells, and cancer can start practically somewhere (Galanki *et al*, 2022).

Origin of Cancer

Cancer's origin every kind of cancer starts in cells, which are the fundamental building blocks of life in the body. To maintain the body's health, these cells divide and expand in a controlled manner. (Lalla *et al*, 2013)

Tumours: As previously mentioned, a tumour is a lump or growths of tissues composed of aberrant cells. Benign and malignant are the two sorts.

Benign Tumours: These can develop in different bodily areas. Benign tumours do not infiltrate or spread to other tissues; instead, they grow slowly. They are often not life-threatening and are not malignant. But certain benign tumours can be problematic.

Malignant Tumours: Malignant tumours have a propensity to spread swiftly and infiltrate surrounding tissues and organs, potentially causing harm. The main tumour is the original place where tumours typically originate. (Lalla *et al*, 2013)

Type of Cancer

- **Carcinoma**: Around 80–90% of complete cancer cases are carcinomas, which is malignancies of epithelial tissues that typically affect organs or glands that can secrete, such as the breasts, lungs, colons, prostates, bladders, etc.
- **Sarcoma:** Another kind of cancer that starts in supportive and connection tissues such bone, tendons, cartilages, muscles, and fat is called sarcoma. Sarcomas include osteosarcoma, chondrosarcoma, leiomyosarcoma, and others.
- **Myeloma:** The excess production of undeveloped WBC (white blood cells is connected with myeloma, which starts in the bone marrow plasma cells.
- **Lymphoma:** Lymphomas, sometimes referred to as "solid cancers," arise in the lymphatic system's nodes or glands, which are involved in the creation of lymphocytes and the purification of body fluids.
- **Mixed Types**: Teratocarcinoma, carcinosarcoma, mixed mesodermal tumour, and adenosquamous carcinoma are examples of mixed forms. (Bordoloi *et al*, 2026)

Cause of Cancer

Cancer causes three primary gene types are impacted by genetic alterations. These are DNA reparation genes, tumour suppresser genes, and proto-oncogenes. (Keith Clinton Howell 2016).

- **Physical Carcinogens:** Ionising radiation contains uranium, radon, sunrays UV light, and radiation from bases that release beta, gamma, X ray and alpha radiation.
- **Chemical Carcinogens:** includes substances that is n-nitrosamines, asbestos, benzidine, cadmium, benzene, nickel, vinyl chloride, and as well as roughly 60 recognized influential carcinogens or compounds from tobacco usage or smoking cigarettes, drinking H_2O contaminants that is arsenic, and food pollutants like aflatoxin.
- **Biological Carcinogens:** humanoid papillomavirus (HPV), Epstein-Barr virus (EBV), hepatitis B, C, Kaposi's sarcoma allied herpesvirus (KSHV), Markel cell polyomavirus, Schistosoma spp., Helicobacter pylori, and other infections caused by specific bacteria, viruses, or parasites. (Saini *et al*, 2020)

Oncogenes and Tumor Suppressor Genes

Oncogenes and tumour suppressor genes are two particularly significant families of genes linked. Normal genes called tumour suppresser genes lower down cell division, fix errors in DNA, and signal when cells should dead, apoptosis or PCD. (Lalla *et al*, 2013).

Chemical Carcinogens

Chemicals, radiation, and other substances that can harm cells and increase the likelihood that they will develop into malignant cells are known as carcinogens. The smoke from tobacco, including formaldehyde, benzene, asbestos, and many others. (Lalla et al, 2013).

Treatment

- **Nanomedicine:** Because of that is minor size and large surface-to-volume ratio, nanoparticles which range in size from 1 to 1,000 nm have unique physicochemical characteristics. Targeting nanoparticles can be done passively or actively.
- **Extracellular Vesicles for Cancer Treatment:** Two types of extracellular vesicles (also known as microvesicles, with a diameter of 100–1000 nm) are exosomes (50–100 nm) and ectosomes.
- **Natural Antioxidants in Cancer Therapy:** A flavonoid with antiviral, anti-inflammatory, anti-allergic, anti-cancer and antioxidant qualities is quercetin. Quercetin has been demonstrated to decrease malignancies of the breast, lung, nasopharynx, kidney, colon, prostate, pancreas, and ovaries.

- **Gene Therapy for Cancer Treatment:** One potential application is the introduction of a well gene into the cells of individuals with a "maltiworking" gene in order to treat genetic diseases.
- **Stem Cell Therapy:** The ability of stem cells from different sources to proliferate, migrate, and differentiate determines the anti-tumor therapeutic uses of these cells. Stem cells have a strong propensity for replication and the capacity to self-renew during multilineage differentiation.
- **Drug-Free Treatments:** Non-pharmacological therapies that could improve your quality of life while receiving cancer treatment include yoga, massage, meditation, and hypnosis.
- **Chemotherapy Drugs and Treatment:** Chemotherapy is the systemic usage of drugs or chemicals to destroy cancers cells. a) alkylating agents b) antimetabolites c) antibiotics d) Total topoisomerase stop. (Galanki *et al*, 2022).

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The Human Pursuit of Survival

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View Point

Nature worshipped humans, an animal species, with the ability to think, react, and improvise. The evolution of modern man marked the modern era of the Earth's ecosystem; it was the commencement of the conquest of humans on Earth. Since then, humans have been thinking, reacting, and improvising for the betterment of human existence. I always wonder about the first mother or father who prepared curd from milk; such a person can be considered among those who laid the foundation of future modern biotechnology. Humans are animals that continually strive to invent things for the overall well-being of the human species as a whole. We learned to captivate animals for our use, for getting milk and wearing warm clothes made from their wool. We have done everything possible to survive on this Earth. The birth of biotechnology and allied aspects of science was a key factor in the human attempt at improvisation. Imagine how Alexander Fleming could invent penicillin. We can say that if Fleming had not invented penicillin in the late 1920s, then I, as the writer of this article, and half of its readers would not be here, as the discovery of penicillin paved the way for the development of numerous other antibiotics[2]. People would have died from common colds leading to pneumonia. For the very fortune of humanity, that discovery was also supposed to be accidental[5].

At the onset of the first decade of the 20th century, there was a situation where a massive number of people were dying from diseases like pneumonia, tuberculosis, and sepsis because antibiotics had not yet been discovered. It was the time when Alexander Fleming started his career at St. Mary's Hospital in London. He spent many years working on bacteria there. Later, during the First World War, he served as a captain in the Royal Army Medical Corps. While treating injured soldiers, he observed that some bacteria were not effectively controlled by the standard medicines available at that time[4]. So he started extensive work on controlling bacterial populations, especially *Staphylococcus*. One day before going on vacation, he accidentally left some cultures of bacteria in a Petri dish. When he returned after the vacation, he noticed something unusual. The Petri dish that had been left with cultures was contaminated by a mold fungus. But surprisingly, the bacterial populations around the mold were destroyed. This caught his attention, and instead of throwing away the Petri dish, he started analyzing it. He discovered that the fungal mold he observed on the Petri dish was *Penicillium notatum*. This fungal mold had produced a substance that killed bacteria. He called this substance penicillin and reported his discovery in 1929 in the *British Journal of Experimental Pathology*. However, since penicillin was difficult to isolate and it was tedious to produce it in large quantities, this discovery remained unnoticed for several years. After a few years, Florey and Chain continued this work at Oxford University and developed simpler methods to isolate penicillin and produce it on a large scale. This continuation of research rejuvenated antibiotic research. Antibiotics, especially penicillin, proved to be the "miracle drug" in World War II. During World War II, the demand for antibiotics increased greatly. The United States and Britain together carried out a huge program on industrial fermentation technology to produce penicillin. Penicillin was extensively used to treat wounded soldiers and saved many lives during the war. In 1945, Fleming, Florey, and Chain received the Nobel Prize in Physiology or Medicine[10]. If we consider the entire chronology of the discovery of penicillin, humankind would definitely be thankful to Fleming and his coworkers. The discovery of penicillin right before World War II saved many lives[3].

Another important discovery of Alexander Fleming was overshadowed by the discovery of penicillin, yet the story of that discovery is also notable. During his research on bacteria and bacterial infections at St. Mary's Hospital, London, nasal mucus accidentally fell into a bacterial culture plate. Again, to his surprise, he observed that bacteria around the mucus were dissolved or inhibited. He investigated this observation and found that there are certain enzymes in human saliva, mucus, and tears that have antibacterial properties. These enzymes are capable of breaking the cell walls of certain bacteria; hence they were named lysozymes. Though lysozymes cannot treat severe infections, the occurrence of such substances in certain human body fluids proved the existence of natural antimicrobial immunity, which helped further studies in this regard. Earth has experienced the continuous struggle of humans to discover things that would support our prolonged existence on this planet. Timely inventions and discoveries have helped us survive in various conditions. Another researcher, Katalin Karikó, in the 1990s, started working on mRNA. She proposed that mRNA could be used as medicine, but many researchers in the field rejected this idea on the grounds of probable autoimmunity against mRNA. Still, she continued working on this concept[6].

In 2005, collaborating with Drew Weissman, Katalin Karikó developed a method to safely introduce mRNA into target cells by modifying nucleosides. These changes enabled efficient protein production without harmful immune reactions[7]. Initially overlooked, this breakthrough gained global importance during the COVID-19 pandemic, when rapid vaccine development was essential[9]. Their discovery allowed scientists to create effective mRNA vaccines in record time, helping humanity combat the crisis. In recognition of this work, Karikó and Weissman were awarded the 2023 Nobel Prize in Physiology or Medicine[1, 8]. This innovation has since opened new possibilities for treating serious diseases, including cancer, by enabling advanced therapeutic approaches using mRNA technology.

Human intelligence has driven scientific progress through crises like the plague, world wars, and COVID-19, helping preserve life and ensure food security. Today, artificial intelligence is emerging as a powerful tool, already influencing biotechnology. AI can enhance vaccine design, predict protein structures, and potentially identify disease-causing genes to develop effective therapies. Biotechnology remains vital for sustaining life on Earth, particularly human existence. Continued research integrating AI with biotechnology promises to improve quality of life. However, this progress must align with nature, ensuring sustainable development while advancing scientific innovation for the betterment of humanity.

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Preliminary Taxonomic Studies on Weed flora of Marathwada Region of Maharashtra State

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Abstract

Unwanted plant species that grow under natural environmental conditions are commonly referred to as weeds. Weed diversity in agricultural fields largely depends on agricultural practices such as irrigation patterns, topography, fertilizer application, socio-economic conditions, spraying regimes, and habitat diversity. Weeds act as primary competitors to crops, lawns, orchards and gardens, causing significant economic losses and posing major challenges to agricultural productivity. The present study was conducted to document and analyze weed diversity in the Marathwada region of Maharashtra State, India. A total of 130 weed species were recorded and studied with respect to their morphology, flowering and fruiting seasons, weed types, present occurrence with ecological notesand medicinal importance. The findings contribute to a better understanding of regional weed flora and provide baseline data for effective weed management strategies.

Keywords: Agriculture, Angiosperm, Weeds, Balaghat Ranges, Maharashtra, India.

Introduction

Weeds are a major biotic stress in Indian agriculture, competing with crops for nutrients, water, and light, causing significant yield and quality losses. In Marathwada, weeds are classified as monsoon or autumn weeds. Monsoon weeds flourish during Kharif crops, while autumn weeds persist with Rabi crops. Common species include *Ageratum conyzoides*, *Alternanthera sessilis*, *Euphorbia hirta*, *Cleome viscosa*, *Portulaca oleracea*, and *Xanthium indicum* (Jagtap, 1965, 1966; Naik, 1979, 1998; Patunkar, 1980; Gore, 2015). The region receives ~882 mm annual rainfall, but irregular rains and frequent droughts limit productivity. Irrigation relies on wells and temporary reservoirs, with wetlands supporting dense weed flora. Effective management, including weeding, mulching, and selective herbicide use, reduces crop losses. Many weeds also provide fodder or medicinal resources, supporting sustainable agriculture (Almeida, 1996, 2009; Singh & Karthikeyan, 2000; Dhole et al., 2009; Gaikwad et al., 2012, 2014).

Materials and Methods

Study Area

The Marathwada region, part of Maharashtra's Deccan Plateau, spans 64,590 km² across eight districts, with elevations of 300–792 m. Sloping west to east, it lies between the Godavari and Krishna watersheds, receiving ~882 mm annual rainfall. Its dry, extreme climate supports tropical dry deciduous forests, scrublands, and grasslands, hosting over 100 bird species, including the Great Indian Bustard. These ecosystems sustain biodiversity and economically important plants, contributing to ecological and agricultural value (Almeida, 1996; Singh & Karthikeyan, 2000; Gaikwad et al., 2012).

Data Collection

The weed flora of Marathwada, Maharashtra, was documented through extensive field surveys across Kharif and Rabi seasons in both irrigated and non-irrigated fields. Observations included plant habits, habitats, flower traits, geographic coordinates, local names, and medicinal uses. Key species were collected, preserved using conventional herbarium methods (Jain & Rao, 1960; Rao & Sharma, 1990), and stored at Walchand College, Solapur. Taxonomic identities and nativity were confirmed using literature (Naik, 1979, 1998; Patunkar, 1980; Almeida, 1996–2009; Singh & Karthikeyan, 2000; Dhole et al., 2009; Gaikwad et al., 2012, 2014; Gore, 2015), as well as online databases including POWO, IPNI, and WFO. Ambiguous specimens were verified against authenticated e-herbarium records.

Table 1. List of weed species [WL-Wasteland, RS- along Roadside, CF-Crop Field, F-Forest, FE-Forest Edges, SF-Scrub Forest, GS-Grassy Slopes, GL- Grasslands.]

Sr	Weed Species	Family	Habitat	Habit
1.	*Abuliton indicum*	Malvaceae	RS	Under Shrubs
2.	*Achyranthes aspera*	Amaranthaceae	WL, RS, CF	Under Shrubs
3.	*Aerva lanata*	Amaranthaceae	RS, WL, FE	Under Shrubs
4.	*Aeschynomene indica*	Fabaceae	CF, SF, GL	Herbs
5.	*Ageratum conyzoides*	Asteraceae	F, RS, WL, CF	Herbs
6.	*Alternanthera pungens*	Amaranthaceae	CF	Herbs
7.	*Alternanthera sessilis*	Amaranthaceae	CF, RS, WL	Herbs
8.	*Alysicarpus* spp.	Fabaceae	WL, CF	Herbs

9.	*Amaranthus spinosus*	Amaranthaceae	CF, RS, WL	Herbs
10.	*Amaranthus viridis*	Amaranthaceae	CF, RS, WL	Herbs
11.	*Ammannia baccifera*	Lythraceae	CF	Herbs
12.	*Anagallis arvensis*	Primulaceae	CF, RS, WL	Herbs
13.	*Anaphalis contorta*	Asteraceae	F, GS	Herbs
14.	*Anaphalis nepalensis*	Asteraceae	F, GS	Herbs
15.	*Anisomeles indica*	Lamiaceae	RS, WL, SF	Under Shrubs
16.	*Apluda mutica*	Poaceae	SF, F, RS	Herbs
17.	*Argemone mexicana*	Papaveraceae	RS, WL	Herbs
18.	*Artemisia nilagirica*	Asteraceae	RS, FE, WL	Under Shrubs
19.	*Avena sativa*	Poaceae	CF, RS, WL	Herbs
20.	*Bidens pilosa*	Asteraceae	CF, WL	Herbs
21.	*Boerhavia diffusa*	Nyctaginaceae	WL, RS	Herbs
22.	*Cannabis sativa*	Cannabinaceae	WL, RS, CF	Herbs
23.	*Capsella bursa-pastoris*	Brassicaceae	WL, RS, CF	Herbs
24.	*Cardamine impatiens*	Brassicaceae	WL, CF	Herbs
25.	*Cardiospermum halicacabum*	Sapindaceae	RS, WL	Herbs
26.	*Cassia occidentalis*	Caesalpiniaceae	WL, RS, CF	Under Shrubs
27.	*Cassia pumila*	Caesalpiniaceae	CF, RS, WL	Herbs
28.	*Cassia tora*	Caesalpiniaceae	CF, RS, WL	Under Shrubs
29.	*Cassia uniflora*	Caesalpiniaceae	CF	Herbs
30.	*Celosia argentea*	Amaranthaceae	CF, RS	Herbs
31.	*Centella asiatica*	Apiaceae	RS, FE	Herbs
32.	*Chenopodium album*	Chenopodiaceae	CF, RS, WL	Herbs
33.	*Chenopodium ambrosioides*	Chenopodiaceae	RS, WL	Herbs
34.	*Chinopodium murale*	Chenopodiaceae	CF, WL	Herbs
35.	*Chloris barbata*	Poaceae	RS	Herbs
36.	*Cleome viscosa*	Cleomaceae	CF, RS, WL	Herbs
37.	*Commelina forsskalii*	Commelinaceae	CF, RS, WL	Herbs
38.	*Convolvulus arvensis*	Convolvulaceae	CF, RS, WL	Climbers
39.	*Conyza bonariensis*	Asteraceae	CF, RS, WL	Herbs
40.	*Conyza canadensis*	Asteraceae	CF, RS, WL	Herbs
41.	*Corchorus aestuans*	Tiliaceae	SF, RS, WL	Herbs
42.	*Coronopus didymus*	Brassicaceae	WL, CF, FE	Herbs

43.	*Crassocephalum crepidioides*	Asteraceae	F, WL, RS	Herbs
44.	*Crotalaria spectabilis*	Fabaceae	FE, CF, RS	Under Shrubs
45.	*Cyanotis cristata*	Commelinaceae	WL, CF	Herbs
46.	*Cynadon dactylon*	Poaceae	WL, CF, RS, F	Herbs
47.	*Cynoglossum lanceolatum*	Boraginaceae	RS, WL, FE	Herbs
48.	*Cynoglossum zeylanicum*	Boraginaceae	WL, FE, GS	Herbs
49.	*Cyperus compressus*	Cyperaceae	CF	Herbs
50.	*Cyperus difformis*	Cyperaceae	CF	Herbs
51.	*Cyperus iria*	Cyperaceae	CF, WL	Herbs
52.	*Cyperus niveus*	Cyperaceae	CF, GS	Herbs
53.	*Cyperus rotundus*	Cyperaceae	CF, WL	Herbs
54.	*Dactyloctenium aegypticum*	Poaceae	RS, WL, CF	Herbs
55.	*Datura innoxia*	Solanaceae	WL, RS	Herbs
56.	*Datura stramonium*	Solanaceae	WL, RS	Herbs
57.	*Desmodium microphyllum*	Fabaceae	CF, FE	Herbs
58.	*Desmodium triflorum*	Fabaceae	RS, CF, GL	Herbs
59.	*Dichanthium caricosum,*	Poaceae	WL, CF, GS	Herbs
60.	*Digitaria ciliaris*	Poaceae	RS, WL, CF	Herbs
61.	*Echinochloa colona*	Poaceae	CF	Herbs
62.	*Echinochloa crus-galli*	Poaceae	CF	Herbs
63.	*Eclipta prostrata*	Asteraceae	CF, WL	Herbs
64.	*Eleocharis atropurpurea*	Cyperaceae	CF	Herbs
65.	*Eleusine indica*	Poaceae	CF, RS, WL	Herbs
66.	*Emilia sonchifolia*	Asteraceae	CF, RS, WL	Herbs
67.	*Eragrostis unioloides*	Poaceae	CF, RS, WL	Herbs
68.	*Erigeron sublyratus*	Asteraceae	RS	Herbs
69.	*Eriocaulon duthi*	Eriocaulaceae	CF	Herbs
70.	*Eupatorium adenophorum*	Asteraceae	RS, F, WL	Under Shrubs
71.	*Euphorbia heterophylla*	Euphorbiaceae	CF, WL	Herbs
72.	*Euphorbia hirta*	Euphorbiaceae	CF, RS, WL	Herbs
73.	*Euphorbia hypericifolia*	Euphorbiaceae	WL, CF	Herbs
74.	*Euphorbia prostrata*	Euphorbiaceae	WL, CF	Herbs
75.	*Evolvulus alsinoides*	Convolvulaceae	WL, F	Herbs
76.	*Fimbristylis dichotoma*	Cyperaceae	CF	Herbs

77.	*Fimbristylis miliacea*	Cyperaceae	CF	Herbs
78.	*Gnaphalium luteo-album*	Asteraceae	CF, WL, FE	Herbs
79.	*Gnaphalium polycoulon*	Asteraceae	WL, RS, F, FE	Herbs
80.	*Gomphrena celosioides*	Amaranthaceae	CF, RS, WL	Herbs
81.	*Hedyotis corymbosa*	Rubiaceae	WL, CF	Herbs
82.	*Imperata cylindrica*	Poaceae	FE, GS, WL	Herbs
83.	*Indigofera glandulosa*	Fabaceae	CF, RS	Herbs
84.	*Ipomoea nil*	Convolvulaceae	SF, WL, FE	Climbers
85.	*Ipomoea pes-tigridis*	Convolvulaceae	WL, CF, F, RS	Climbers
86.	*Ipomoea purpurea*	Convolvulaceae	WL, CF	Climbers
87.	*Ischaemum rugosum*	Poaceae	CF, RS	Herbs
88.	*Justicia procumbens* L.	Acanthaceae	CF, WL, RS	Herbs
89.	*Kyllinga nemoralis*	Cyperaceae	CF, RS	Herbs
90.	*Lactuca dissecta*	Asteraceae	WL, CF	Herbs
91.	*Lantana camara*	Verbenaceae	F, RS, WL	Shrubs
92.	*Lathyrus sativa*	Fabaceae	CF, WL	Herbs
93.	*Lindenbergia indica*	Scrophulariaceae	GS	Herbs
94.	*Martynia annua*	Martyniaceae	WL, RS	Herbs
95.	*Melilotus indica*	Fabaceae	RS, CF, WL	Herbs
96.	*Merremia emarginata*	Convolvulaceae	WL, F	Climbers
97.	*Mirabilis jalapa*	Nyctaginaceae	WL, RS	Herbs
98.	*Murdannia nudiflora*	Commelinaceae	RS, GL, CF	Herbs
99.	*Oplismenus compositus*	Poaceae	F, RS	Herbs
100.	*Oxalis corniculata*	Oxalidaceae	CF, WL	Herbs
101.	*Panicum psilopodium*	Poaceae	CF, FE	Herbs
102.	*Parthenium hysterophorus*	Asteraceae	CF, WL, RS, F	Herbs
103.	*Paspalidium flavidum*	Poaceae	CF, WL, RS	Herbs
104.	*Paspalum distichum*	Poaceae	CF, RS	Herbs
105.	*Peristrophe paniculata*	Acanthaceae	WL, RS	Herbs
106.	*Persicaria capitata*	Polygonaceae	WL	Herbs
107.	*Persicaria nepalensis*	Polygonaceae	CF, RS	Herbs
108.	*Phalaris minor*	Poaceae	RS, CF	Herbs
109.	*Phyllanthus niruri*	Euphorbiaceae	WL, RS, CF	Herbs
110.	*Physalis minima*	Solanaceae	WL, CF, RS	Herbs
111.	*Polygonum barbatum*	Polygonaceae	WL, CF	Herbs
112.	*Polygonum plebeium*	Polygonaceae	WL, CF, RS	Herbs

113.	*Portulaca oleracea*	Portulacaceae	CF, WL	Herbs
114.	*Portulaca pilosa*	Portulacaceae	RS, WL	Herbs
115.	*Rumex dentatus*	Polygonaceae	WL, RS	Herbs
116.	*Setaria glauca*	Poaceae	RS, WL, CF	Herbs
117.	*Setaria pumila*	Poaceae	RS, WL, CF	Herbs
118.	*Sida acuta*	Malvaceae	WL, RS, SF	Herbs
119.	*Sida cordifolia*	Malvaceae	WL, RS, FE	Under Shrubs
120.	*Sida rhombifolia*	Malvaceae	WL, RS, FE	Herbs
121.	*Solanum anguvi*	Solanaceae	RS, WL	Under Shrubs
122.	*Solanum virginianum*	Solanaceae	RS, WL, CF	Herbs
123.	*Sonchus oleraceus*	Asteraceae	RS, WL, CF	Herbs
124.	*Tricholepis glaberrima*	Asteraceae	RS, WL, CF	Herbs
125.	*Tridax procumbens*	Asteraceae	RS, WL, CF	Herbs
126.	*Trifolium repens*L.	Fabaceae	CF, WL	Herbs
127.	*Triumfetta malbarica*	Tiliaceae	RS, WL, FE	Under Shrubs
128.	*Verbascum chiense*	Scrophulariaceae	WL, RS, GS	Herbs
129.	*Veronica persica*	Scrophulariaceae	CF, WL	Herbs
130.	*Xanthium indicum*	Asteraceae	WL, RS, CF	Herbs

Conclusion

The taxonomic study of Marathwada's weed flora recorded 130 species across 96 genera and 33 families, with 116 dicots and 33 monocots. Herbaceous weeds dominate (85.56%), followed by undershrubs, climbers, and shrubs. Asteraceae (20 species) and Poaceae (20 species) are most prevalent. Many species occur in wastelands and have ethnobotanical uses, serving as fodder or in Ayurvedic medicine (Dhole et al., 2009). Anthropogenic disturbances promote invasive weed proliferation.

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