DEPARTMENT OF AGRICULTURE DEVELOPMENT
& FARMERS' WELFARE, GOVERNMENT OF KERALA

FARM INFORMATION BUREAU

KERALA KARSHAKAN

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

E-JOURNAL

AUGUST 2026
VOLUME 14 ISSUE 03

FEEDING CROPS THROUGH WATER SPONGE

INNOVATION IN AGRICULTURE:

SHAPING A SUSTAINABLE FUTURE

INSIDE

KERALAKARSHAKAN

AUGUST 2026 • VOLUME 14 • ISSUE 03

Mail editorejournalkkfib@gmail.com Log on to www.fibkerala.gov.in Phone: 0471 2314358

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

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Innovations in Agriculture: Shaping a Sustainable Future

Emerging technologies, climate resilience, and value addition for tomorrow's agriculture.

EDITORIAL

Agriculture today is witnessing a remarkable transformation driven by scientific innovation, sustainable technologies, and value-added solutions. As farming systems respond to the challenges of climate change, water scarcity, changing consumer preferences, and resource limitations, research is playing an increasingly vital role in developing practical solutions that improve productivity while protecting natural resources. From laboratory innovations to field-level applications, modern agricultural science is opening new opportunities for resilient and profitable farming.

This issue of Kerala Karshakan e-Journal brings together a collection of articles that showcase these emerging advancements. Readers will explore how technology commercialization can bridge the gap between research and real-world adoption, the role of hydrogels in efficient water management, innovative grafting techniques for black pepper, and the untapped potential of the Curcuma family. The issue also highlights the nutritional and commercial significance of corn silk, okra, and makhana, alongside sustainable industrial technologies such as enzyme-assisted cassava starch extraction, biochar-based wastewater treatment, and pulsed electric field technology for food preservation. Together, these articles demonstrate how science is creating practical, scalable, and environmentally responsible solutions for agriculture and the agri-food sector.

We hope this edition inspires researchers, extension professionals, entrepreneurs, students, and progressive farmers to embrace innovation and translate knowledge into action. By connecting scientific research with practical application, we can build an agricultural future that is productive, resilient, sustainable, and capable of meeting the needs of generations to come.

Technology Commercialization: Prospects and Challenges

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Abstract

Technology commercialization is the process of transforming scientific research, innovative ideas and technological inventions into marketable products, services, or processes that create economic and social value. It serves as a bridge between research institutions, industries, entrepreneurs and end users by ensuring that innovations reach the marketplace and benefit society. In agriculture, healthcare, manufacturing, information technology and other sectors, commercialization plays a vital role in improving productivity, creating employment opportunities and promoting sustainable development. Despite significant advancements in research and innovation, many technologies fail to reach the market due to inadequate funding, weak industry academia collaboration, regulatory barriers, intellectual property issues and limited market awareness. At the same time, supportive government policies, startup ecosystems, digital transformation and increasing private sector participation have created new opportunities for successful commercialization. This article discusses the concept of technology commercialization, its importance, prospects, challenges and strategies for strengthening the commercialization ecosystem, particularly in the Indian context.

Keywords:
Technology commercialization, innovation, startups, intellectual property.

Introduction

Scientific research and technological innovations are valuable only when they are successfully translated into products and services that improve people's lives. Universities, research institutions and industries continuously generate new technologies, but many innovations remain confined to laboratories because they fail to reach the marketplace. Technology commercialization plays a vital role in converting these innovations into commercially viable products that create economic and social benefits.

In agriculture, commercialization of improved crop varieties, biofertilizers, biocontrol agents, farm machinery, food processing technologies and renewable energy-based equipment has significantly improved farmers' income and productivity. Therefore, strengthening technology commercialization has become an important component of innovation-led development.

What is Technology Commercialization?

Technology commercialization is the process of converting a new technology, invention, or research outcome into a product, process, or service that can be successfully introduced and sold in the market. It bridges the gap between scientific research and practical application, ensuring that innovations benefit society while generating economic value.

The commercialization process typically involves identifying a promising technology, protecting it through intellectual property rights (such as patents), developing a prototype, testing and refining the product, securing funding, obtaining regulatory approvals if required, manufacturing, marketing and finally launching it in the market. Successful commercialization benefits researchers, industries, consumers and the economy by creating jobs, encouraging innovation and improving quality of life.

Example: Technology commercialization of automatic water pump visually represented in figure 1

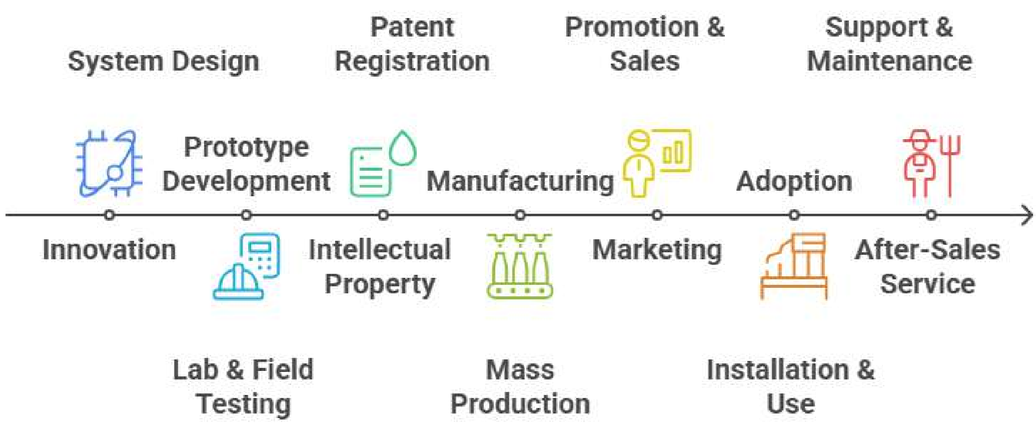

Figure 1. Technology commercialization of automatic water pump

Understanding Technology Commercialization

Technology commercialization is a systematic process that transforms a research idea or scientific discovery into a product, service, or technology that can be successfully introduced into the market. It involves a series of planned activities, beginning with the identification of a promising innovation and continuing through intellectual property protection, evaluation, industry collaboration, licensing and commercialization. Each stage plays a vital role in reducing technical and commercial risks while ensuring that the innovation meets market needs and generates value for inventors, industries and society. The major steps involved in technology commercialization are outlined below in figure 2.

Steps in Technology Commercialization

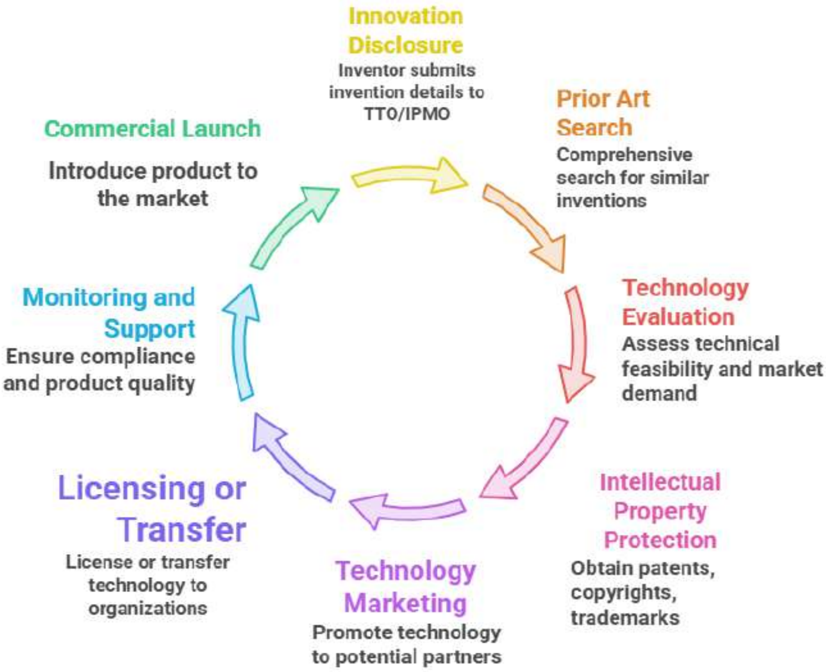

Figure 2. Steps in Technology Commercialization

Opportunities and Prospects

Technology commercialization has emerged as a powerful driver of innovation-based economic development. By converting scientific knowledge into practical applications, it creates value for researchers, industries, entrepreneurs and society. Commercialization encourages the establishment of technology-based start-ups, stimulates investment in research and development and strengthens collaboration between academic institutions and industries. It also improves industrial productivity by enabling the adoption of advanced technologies and enhances national competitiveness in global markets. In agriculture, commercialization of innovative technologies contributes to increased crop productivity, efficient resource utilization, climate resilience, improved food quality and higher farm income. The growing emphasis on innovation ecosystems, incubators and entrepreneurial support programmes provides India with significant opportunities to emerge as a global leader in technology commercialization.

Institutional Support for Technology Commercialization in India

1. National Research Development Corporation (NRDC)

- Assists researchers in protecting intellectual property (IP).
- Facilitates transfer of indigenous technologies to industries.
- Supports commercialization of research outcomes.

2. Technology Information, Forecasting and Assessment Council (TIFAC)

- Promotes technology development and assessment.
- Supports demonstration projects.
- Encourages commercialization of technologies, especially for MSMEs.

3. Technology Development Board (TDB)

- Provides financial assistance for commercialization of indigenous technologies.
- Supports research organizations and industries in bringing innovations to market.

4. National Science and Technology Entrepreneurship Development Board (NSTEDB)

- Promotes technology-based entrepreneurship.
- Supports innovation-driven startups and enterprises.
- Encourages the development of technology business incubators.

5. Start-up India

- Encourages startup creation and innovation.
- Provides funding support, mentorship and regulatory benefits.
- Promotes commercialization of innovative ideas.

6. Make in India

- Promotes domestic manufacturing and innovation.
- Encourages industry–research collaboration.
- Supports commercialization of indigenous technologies.

7. Digital India

- Promotes digital infrastructure and digital technologies.
- Supports technology adoption and digital entrepreneurship.
- Facilitates technology transfer through digital platforms.

8. Atal Innovation Mission (AIM)

- Promotes innovation and entrepreneurship across India.
- Establishes incubation centers and Atal Tinkering Labs.
- Supports startups in developing and commercializing innovative technologies.

Challenges in Technology Commercialization

Before discussing the challenges, it is important to recognize that technology commercialization is a complex and multidisciplinary process involving scientific, technical, financial, legal and market-related activities. The successful transformation of an innovation into a commercially viable product requires strong institutional support, adequate funding, effective industry collaboration, intellectual property protection and a favorable policy environment. However, several obstacles often hinder this process, limiting the successful transfer of research outcomes from laboratories to the marketplace.

Although technology commercialization offers tremendous opportunities, several constraints continue to affect its success, this challenges are listed below in figure 3.

Figure 3. Challenges of Technology Commercialization

Future Perspectives

Strengthening technology commercialization requires coordinated efforts from governments, research institutions, industries, investors and entrepreneurs. Greater emphasis should be placed on strengthening university–industry collaborations, expanding Technology Transfer Offices, simplifying intellectual property procedures and improving access to commercialization finance. Entrepreneurship education and innovation management training should become integral components of higher education to equip researchers with commercialization skills. Establishing stronger incubation facilities, promoting market-oriented research, encouraging interdisciplinary collaboration and developing supportive policy frameworks will further accelerate the successful translation of scientific discoveries into commercially viable technologies.

Conclusion

Technology commercialization is an essential component of modern innovation systems because it transforms research into solutions that generate economic, social and environmental value. It enables scientific discoveries to reach industries, farmers and consumers while promoting entrepreneurship, employment generation and sustainable development. India possesses a strong scientific base, an expanding start-up ecosystem and supportive government initiatives that provide favourable conditions for commercialization. By improving intellectual property management, strengthening partnerships between academia and industry, expanding financial support and promoting entrepreneurial culture, the country can effectively bridge the gap between research and the marketplace. A robust commercialization ecosystem will ensure that innovations not only remain scientific achievements but also become practical solutions that contribute meaningfully to national progress and societal well-being.

HYDROGELS: FEEDING CROPS THROUGH WATER SPONGE

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Agriculture is facing unprecedented challenges due to increasing water scarcity, climate variability, and soil degradation, which collectively threaten global food security. In many developing nations, including India, agricultural production relies heavily on rainfall, making farming systems particularly vulnerable to drought and erratic precipitation patterns. Under such conditions, conventional irrigation practices alone are often inadequate to sustain crop productivity, highlighting the need for innovative and resource-efficient water management strategies. Hydrogels, commonly referred to as superabsorbent polymers, have emerged as a promising technology for sustainable agriculture because of their exceptional ability to absorb, retain, and gradually release large quantities of water in response to the demand of the crop. In addition to improving the availability of soil moisture, hydrogels enhance certain soil physical properties, increase nutrient-use efficiency, enable the controlled release of fertilizers and agrochemicals, and promote seed germination, plant growth, and crop productivity. Recent developments in biodegradable and stimuli-responsive hydrogels have further broadened their applications in precision agriculture. Consequently, hydrogels are increasingly recognized as an important component of climate-resilient and resource-efficient agricultural systems.

What are hydrogels?

Hydrogels are three-dimensional cross-linked polymer networks capable of absorbing and storing large quantities of water, often several hundred times their own weight. They contain hydrophilic functional groups such as hydroxyl, carboxyl and amide groups that attract water, while their cross-linked structure prevents them from dissolving in water. When incorporated into the soil, hydrogels function as miniature water reservoirs, absorbing excess moisture during irrigation or rainfall and gradually releasing it as the surrounding soil dries. This sustained release of water helps alleviate moisture stress for plants, particularly during critical stages of crop growth.

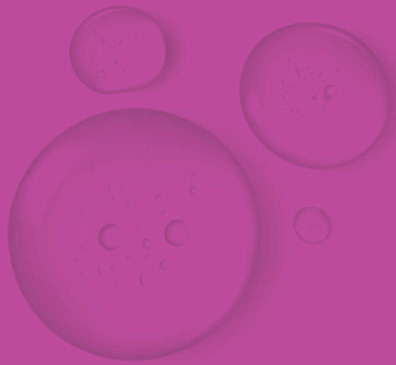
Types of hydrogels

Agricultural hydrogels are broadly classified into synthetic and natural hydrogels. Synthetic hydrogels are mainly prepared from polymers such as polyacrylamide, polyacrylic acid, sodium polyacrylate, and polyvinyl alcohol. They possess excellent water absorption capacity, durability and long service life, making them widely available for commercial agricultural use. At present, majority of the hydrogel products available in the market are synthetic in nature and are used for amending the soil. This large-scale availability is due to their affordability and popularity among farmers. Various hydrogels available in the market are given in Table 1. 'Plant Hydrogel' is a commercially available hydrogel formulated from potassium polyacrylate and exhibits high capacity to absorb water up to 300 times its own weight. This property significantly enhances seed germination and promotes root development in crops

Table 1. Some commercially available hydrogels in market

Commercial hydrogel	Properties	Manufacturer
TRPSORB™	High water absorption capacity, controlled release of nutrients and a long-life cycle	Qingdao SOCO New Material Co., Ltd.
Control Garden	Optimizes water and promotes root growth in hot climates	GrowMania SL (Spain)
Plara	Increases plant drought resistance and improves the quality and size of fruits and vegetables	Plara Sp.z.o.o (Poland)
ALSTA Hydrogel	Absorbs water up to 500 times its weight and it is compatible with all soil and plant types	Chemtex SL (India)
Agua Gel	Biodegradable, decreases irrigation cycles and increase soil porosity	Novingrecons SLU (Spain)
Agrogel	Enables complexation of macronutrients and controlled release of nitrogen via microbial activity	ILSA S.p.A (Italy)
Pusa Hydrogel	Absorbs large amounts of water and retains its water-holding capacity at high temperatures	IARI, New Delhi
Waterlock 93N	Absorbs water up to 100 times its weight, biodegradable, and can be used for 2–3 years	Acuro Organics Ltd., New Delhi

Source: (Granados-Carrera *et al.*,2026)



Natural hydrogels are produced from renewable materials including cellulose, starch, chitosan, alginate, lignin, guar gum, and proteins. They are biodegradable, environmentally friendly, and decompose into harmless substances that enrich soil health. Agricultural wastes such as rice husk, wheat straw, sugarcane bagasse, and tea waste are increasingly being utilized for producing eco-friendly hydrogels.

Biodegradability of hydrogels in soil

One of the common questions farmers ask is whether hydrogels remain in the soil forever. The answer depends on the type of hydrogel that is used. Over time, all types of hydrogels break down through a series of physical, chemical and biological processes. During biodegradation, microorganisms convert the polymer into simpler end products such as water, carbon dioxide. Natural hydrogels are decomposed almost readily by soil microorganisms. Studies show that the degradation of hydrogels does not adversely affect soil fertility or reduce the availability of essential nutrients to plants. This makes biodegradable hydrogels a promising option for sustainable agriculture.

Synthetic hydrogels, such as those made from polyacrylamide or polyacrylate, are more durable and therefore degrade much more slowly. Their breakdown is influenced by factors such as soil moisture, temperature, sunlight, and microbial activity. The degradation of synthetic hydrogels occurs gradually through a combination of natural processes. Sunlight weakens the polymer chains, moisture and oxygen cause chemical changes, and cultivation practices such as tillage and soil movement break the material into smaller fragments. These changes make the polymers more accessible to soil microorganisms, which eventually complete the degradation process.

Hydrogels for water conservation

One of the major advantages of using hydrogels in agriculture, is their exceptional ability to store water. They absorb rainfall or irrigation water using their three-dimensional polymer network. As the surrounding soil dries, the absorbed water is gradually released into the soil due to lower soil water potential. This will minimize the water lost through evaporation, runoff, and deep percolation while maintaining adequate moisture around plant roots. Numerous research works on crops has shown that application of hydrogels had significantly increased the soil moisture content, improved water-use efficiency, and enhanced crop performance under drought conditions. Greater agronomic benefits are achieved when hydrogels are combined with mulching and organic amendments, as these practices act synergistically to conserve soil moisture, improve soil health, and enhance water-use efficiency under water-limited conditions.

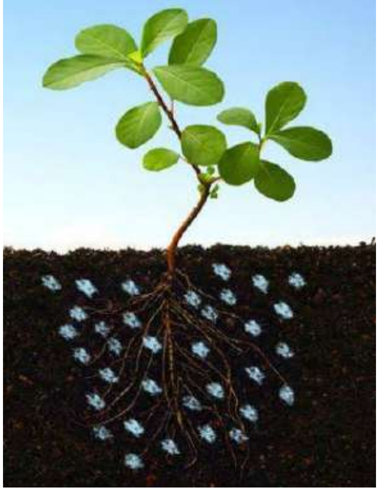
Improvement in seed germination and crop yield

Adequate moisture during germination is essential for successful establishment of crops. Hydrogels maintain a favourable environment around seeds, resulting in earlier and higher germination rates compared with untreated soils. Several studies reported improved germination of wheat, lettuce, and vegetable crops when hydrogels were incorporated into the growing medium. Enhanced moisture availability also promotes better root development and vigorous seedling growth.

Hydrogels also contribute to higher crop yields by maintaining soil moisture during critical growth stages and improving nutrient uptake. Significant yield increase has been reported in wheat and soybean under water-stressed conditions. However, their benefits are generally more pronounced under drought or rainfed conditions than under fully irrigated systems.

Improvement of soil properties

Hydrogels function as effective soil conditioners by reducing the bulk density of soil, thereby improving the soil porosity and enhancing water infiltration. These improvements encourage healthy root growth and increase the soil's capacity to retain moisture. Studies have shown that application of hydrogel had increased the soil porosity while reducing bulk density in both clay loam and sandy loam soils. In addition, hydrogels are chemically inert and generally do not alter soil pH or electrical conductivity when applied at recommended rates.



Controlled release of nutrients and agrochemicals

Conventional fertilizers release nutrients rapidly into the soil, often supplying nutrients at a rate that exceeds the crop's immediate demand. Consequently, a substantial proportion of these nutrients is lost through leaching, surface runoff, volatilization, or soil fixation, resulting in low nutrient-use efficiency, increased production costs, and environmental pollution. One of the most promising applications of hydrogels is their use as carriers for controlled-release fertilizers and pesticides. Nutrients or agrochemicals can be encapsulated within the hydrogel matrix or applied as hydrogel coatings on fertilizer granules. On application to the soil, hydrogels absorb water and swells, gradually releasing the dissolved nutrients in response to soil moisture conditions. This synchronized delivery of water and nutrients ensures a sustained nutrient supply to plants while minimizing nutrient losses. Studies have shown that hydrogel-based fertilizer systems can extend nutrient release from a few hours to several weeks or even months, depending on the hydrogel composition and environmental conditions. As a result, they improve nutrient-use efficiency, reduce nutrient losses through leaching and volatilization, and mitigate environmental pollution. Similar hydrogel-based delivery systems have also been developed for the controlled release of herbicides, fungicides, and other agrochemicals, enhancing their efficacy while reducing application frequency and off-target impacts.

Hydrogels in smart agriculture

Modern agriculture is increasingly integrating hydrogels with smart technologies to enhance resource-use efficiency and support precision farming. Recent advances have led to the development of smart hydrogels capable of harvesting atmospheric moisture during periods of high humidity, such as at night, and automatically releasing the stored water in response to increasing daytime temperatures or soil moisture deficits. In addition, hydrogel-based biosensors have been developed for the rapid detection of residues of pesticides, pathogens and other contaminants directly from the surface of the crop. These sensors can be integrated with portable, smartphone-enabled devices, enabling real-time, on-site monitoring and decision-making. Collectively, these innovations improve irrigation efficiency, reduce labour and input requirements, enhance crop management, and contribute to more sustainable and climate-resilient agricultural production systems.

Challenges and Future Prospects

Despite their advantages, synthetic hydrogels raise environmental concerns because some degrade slowly and may contribute to microplastic accumulation. Excessive application may also influence soil physical and biological properties. Therefore, the development of biodegradable hydrogels derived from natural materials is receiving increased attention. Future research aims to develop smart, biodegradable hydrogels capable of responding to soil moisture, temperature, and pH while integrating with IoT-based sensors and artificial intelligence for precision irrigation and nutrient management. Long-term field evaluation and cost-effective production will be essential for their widespread adoption.

Conclusion

Hydrogels have emerged as a promising technology for sustainable agriculture owing to their excellent water-retention capacity, controlled nutrient-release properties, biodegradability, and positive effects on soil health and crop productivity. Their ability to improve soil moisture, enhance nutrient-use efficiency, promote plant growth, and support beneficial microbial activity makes them valuable tools for addressing key agricultural challenges, particularly in drought-prone and degraded soils. The future of agriculture is not just about growing more. It is about growing smarter. Hydrogels are turning every drop into an opportunity - feeding crops through a water sponge and growing a more sustainable tomorrow.

Reference

Granados-Carrera, C.M., Perez-Puyana, V.M., Jiménez-Rosado, M. and Romero, A. 2026. Hydrogel development, processing and applications in agriculture: a review. Gels 12(3): 259.

Fig. 1. Hydrogel used for agriculture

Fig. 2. Hydrogel applied in soil

Grafting in Black Pepper (Piper nigrum L.): A Sustainable Strategy for Disease Management and Climate Resilience

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Black pepper (Piper nigrum L.), popularly known as the 'King of Spices' and 'Black Gold', is native to the tropical evergreen forests of the Western Ghats of India, with Kerala recognized as its primary centre of origin and domestication. For centuries, the crop has been deeply embedded in Kerala's agriculture, economy and cultural heritage, while serving as the foundation of the historic spice trade. Today, black pepper remains one of Kerala's most important plantation spice crops, cultivated extensively in homesteads, plantations and agroforestry systems, often in association with coconut, arecanut, coffee, tea and other perennial crops. Its adaptability to diversified cropping systems, high economic value and strong export potential make it a vital source of livelihood for thousands of smallholder farmers. Furthermore, its integration into multi-tier cropping systems enhances biodiversity, promotes efficient resource utilization and supports ecological sustainability. Owing to its enduring economic, ecological and strategic significance, black pepper continues to reinforce Kerala's leading position in the global spice sector.

India continues to be one of the world's leading producers, consumers and exporters of black pepper. However, the crop has experienced a steady decline in both cultivated area and productivity in recent years due to escalating biotic and abiotic stresses. According to the Spices Board of India, the area under black pepper cultivation decreased from 312,902 ha with a production of 126,038 MT during 2023–24 to an estimated 288,602 ha with a production of 93,716 MT during 2025–26. Black pepper productivity has declined due to the combined effects of disease outbreaks, pest infestations and climate-induced stresses that adversely affect vine health, yield

and plantation longevity. Among these, foot rot caused by Phytophthora capsici is the most destructive disease, while root-knot nematodes (Meloidogyne incognita) and other soil-borne pathogens contribute to slow decline and severe crop losses. These challenges are further exacerbated by recurrent drought, waterlogging, erratic rainfall and rising temperatures associated with climate change. This declining trend underscores the urgent need for sustainable interventions to improve productivity, enhance crop resilience and ensure the long-term viability of black pepper cultivation.

In response, grafting has emerged as a sustainable propagation strategy to improve black pepper productivity and resilience. Although black pepper is traditionally propagated through rooted stem cuttings, this method facilitates the spread of soil-borne pathogens and offers limited scope for enhancing root system performance. By combining elite, high-yielding scions with vigorous, disease-resistant and stress-tolerant rootstocks, grafting integrates complementary traits into a single plant. Grafted vines exhibit improved establishment enhanced root vigour, greater water and nutrient-use efficiency, increased tolerance to biotic and abiotic stresses and extended productive lifespan. In particular, grafting provides an environmentally friendly alternative for managing devastating diseases such as foot rot and slow decline by utilizing naturally resistant rootstocks, thereby reducing dependence on chemical fungicides and nematicides while maintaining the yield and quality of elite cultivars.

Successful grafting depends largely on the quality of both the rootstock and the scion. In Kerala, Piper colubrinum (Brazilian pepper or wild thippali) is the most widely used rootstock because of its high level of resistance to Phytophthora capsici. The species also exhibits tolerance to root-knot nematodes, temporary waterlogging and several soil-related stresses, making it an excellent rootstock for sustainable black pepper cultivation.

Rootstocks are usually raised from healthy orthotropic (climbing) shoots of Piper colubrinum. Plagiotropic (lateral) shoots are not used because they retain their lateral growth habit. The rooted cuttings are grown in polybags under protected nursery conditions, preferably in a polyhouse. They become suitable for grafting after 3–5 months, when they reach a height of about 60–70 cm and attain sufficient stem thickness. In contrast, plagiotropic shoots are generally used for the production of bush pepper and are unsuitable for raising conventional climbing vines.

Scions are collected from healthy, disease-free, high-yielding cultivars using semi-hardwood orthotropic shoots with three to four nodes. Traditional cultivars such as Karimunda, Kottanadan, Narayakodi, Aimpiriyan, Neelamundi, Kuthiravally, Balankotta, Kalluvally, Tekkan and Valiya Kaniyakadan, along with improved varieties including Panniyur-1 to Panniyur-10, IISR Girimunda and IISR Malabar Excel, constitute valuable scion genotypes for grafting due to their high yield potential, superior quality and wide adaptability.

Several grafting techniques, including cleft, wedge, splice, tongue grafting, have been evaluated in black pepper. Among these, wedge grafting remains the most widely adopted method under commercial nursery conditions

because of its simplicity and reliable performance. Grafting is generally carried out approximately 15 cm above the base of the rootstock, ensuring accurate alignment of the cambial tissues before the graft union is firmly secured with budding or grafting tape. To minimize water loss during graft establishment, the leaf lamina is removed while retaining the petiole.

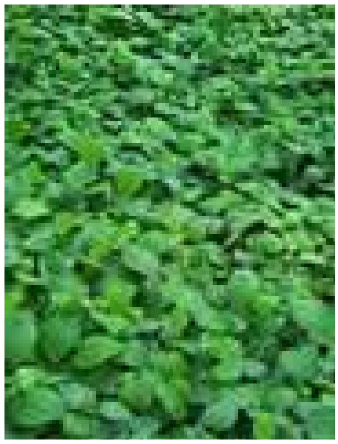
Following grafting, plants are maintained under conditions of high humidity to promote rapid callus formation and vascular reconnection. Healing is commonly achieved by placing grafted plants in mist chambers or by enclosing the graft union within transparent polyethylene sleeves for approximately 15–20 days. Polyhouses equipped with intermittent misting systems or shade houses providing about 50% shade provide favourable environmental conditions for successful graft establishment. Under optimum conditions, sprouting from the scion is usually observed within 20 days, indicating successful graft union.

Proper post-grafting management is essential to ensure successful establishment. Any shoots emerging from the P. colubrinum rootstock below the graft union should be removed periodically to eliminate competition with the scion. Regular irrigation is necessary to maintain adequate soil moisture without causing waterlogging. Although grafting can be undertaken throughout the year under protected nursery conditions, the rainy season generally provides the most favourable environment because of the naturally high atmospheric humidity. Following successful graft union, plants are transferred to a hardening facility before field establishment. Grafted plants are generally ready for transplanting about three months after grafting, after which the grafting tape should be removed. Subsequently, all recommended cultural practices for conventional black pepper cultivation are followed.

Beyond disease management, grafting improves water and nutrient uptake, root architecture, hormonal regulation and stress signalling, thereby enhancing plant vigour, resource-use efficiency and tolerance to drought, temporary flooding and nutrient-deficient conditions. These physiological advantages make grafting a valuable climate-resilient technology for sustaining black pepper productivity while reducing dependence on chemical disease management. Overall, grafting offers a sustainable strategy for improving black pepper production by integrating elite scions with vigorous, disease-resistant rootstocks. Continued advances in rootstock breeding, graft compatibility and nursery management will further strengthen its role in developing resilient and productive black pepper cultivation systems.

FIG 1 piper colubrinum

Fig 2 Grafting knife



Grafted plants

Wedge grafting

Grafts covered with polythene tubes/sleeves

Cover story

Enzyme Assisted Cassava Starch Extraction (EASE): A Sustainable Industrial Technology for Enhancing Cassava Starch Yield and Purity

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Starch is one of the most important polysaccharides utilized in food, pharmaceutical, textile, paper, and biofuel industries. It is commonly extracted from plant sources such as cassava, potato, maize, wheat, and sweet potato. Conventional starch extraction methods primarily rely on mechanical rasping, washing, sieving, and settling processes. However, these methods often result in incomplete release of starch granules due to the presence of cell wall components and intracellular matrices that entrap starch within plant tissues. As a result, considerable starch losses may occur during processing, reducing extraction efficiency and industrial profitability. In the conventional starch production process, starch loss may occur due to incomplete rupture of cells during rasping or grating, fibrous binding of starch granules in the pulp, poor separation efficiency in screening or hydrocyclone systems, escape of fine particles through wastewater, and delays between harvesting and processing that affect cassava tuber quality. The losses become grater when cassava tubers are older, more fibrous, or uneven in maturity, leaving a significant amount of starch trapped in the residue. Enzyme assisted starch extraction (EASE) has emerged as an innovative and environmentally friendly approach to enhance starch recovery. EASE is another new green technique where the addition of enzymes in the extraction medium enhances the recovery. The main purpose of the enzyme in extraction from plant materials is to break or soften the cell walls. The method has gained considerable attention because of its potential to increase starch recovery, reduce processing waste, lower energy consumption, and improve overall process efficiency.

Principle of Enzyme Assisted Starch Extraction:

Cassava tubers contain starch granules enclosed within cells surrounded by complex cell wall structures composed of cellulose, hemicellulose, pectin, lignin, and proteins. During conventional extraction, mechanical disruption alone may not completely break down these structures, leaving a portion of starch trapped within the cellular matrix. Enzyme-assisted extraction employs enzymes that selectively hydrolyze these structural barriers. The degradation of cell wall polysaccharides weakens the tissue matrix and facilitates the liberation of starch granules into the extraction medium. As a result, more starch can be recovered from the same quantity of raw material. The effectiveness of enzyme-assisted extraction depends on factors such as enzyme type, enzyme concentration, incubation time, temperature, pH, substrate characteristics, and the interaction between enzymes and plant tissues.

ENZYMES USED IN STARCH EXTRACTION:

Cellulase

Cellulase hydrolyzes cellulose, the major structural component of cassava tubers. The degradation of cellulose increases cell wall permeability and enhances starch release. Cellulase enzyme can be effectively used in cassava, sweet potato, and cereal starch extraction processes.

Hemi-cellulase

Hemicellulase enzyme degrades hemicellulose, a complex polysaccharide associated with cellulose in cassava fibrous tissues. Their action complements cellulase activity and contributes to more efficient cell wall degradation.

Pectinase

Pectinase enzyme break down pectin substances present in the middle lamella of plant tissues. The hydrolysis of pectin weakens intercellular adhesion, facilitating tissue disintegration and starch liberation. Pectinase enzyme is very effective in root and tuber crops such as cassava and sweet potato.

Protease

Proteases hydrolyze proteins associated with starch granules and cellular structures. They help release starch trapped within protein matrices and improve starch purity by reducing protein contamination.

Enzyme Cocktails

Industrial applications frequently employ combinations of cellulase, pectinase, hemicellulase, and protease. Such enzyme cocktails provide synergistic effects, leading to greater starch recovery than individual enzymes.

EXTRACTION PROCESS

The extraction process generally involves the following steps:

1. Raw Material Preparation

Cassava tubers are cleaned thoroughly to remove soil, debris, and impurities. The material is then peeled and cut into smaller pieces.

2. Size Reduction

The peeled cassava tubers are grated, crushed, or milled to increase the surface area available for enzymatic action.

3. Enzymatic Treatment

The resulting pulp is mixed with water and treated with selected enzymes under controlled conditions. Typical treatment parameters include: Temperature: 35-55°C, pH: 4.0-6.5, Enzyme dosage: Variable depending on substrate and enzyme activity, Incubation time: 30 minutes to several hours. During incubation, enzymes hydrolyze cell wall components and facilitate starch release. Cultivars, maturity stage, starch content, and cell wall composition influence the effectiveness of enzymatic extraction.

4. Sieving

Following enzymatic hydrolysis, the slurry is sieved to separate fiber residues from the starch-rich liquid fraction.

5. Settling or Centrifugation

Starch granules are recovered through settling or centrifugation. The starch is then washed to remove residual soluble impurities.

6. Drying and Packaging

The purified starch is dried using either flash or solar dryer to the desired moisture content and packaged for storage.

FACTORS AFFECTING ENZYME ASSISTED STARCH EXTRACTION

Enzyme Concentration

Increasing enzyme dosage generally enhances cell wall degradation and starch recovery. However, excessive enzyme use may not provide proportional benefits and can increase processing costs.

Temperature

Enzymes exhibit optimal activity within specific temperature ranges. Temperatures above the optimum may cause enzyme denaturation, whereas lower temperatures reduce reaction rates.

pH

The extraction medium must maintain the optimum pH required for maximum enzyme activity. Deviations from the optimum pH can significantly reduce hydrolysis efficiency.

Incubation Time

Sufficient contact time is required for effective degradation of plant tissues. Excessive incubation may increase processing time without significant improvements in yield.

Advantages of Enzyme Assisted Starch Extraction:

Enhanced Starch Yield

The primary advantage is increased starch recovery due to improved liberation of starch granules from fibrous cassava tubers.

Improved Starch Purity

Enzymatic treatment reduces contamination from proteins, fibers, and other non-starch components, resulting in higher quality starch.

Reduced Waste Generation

More complete utilization of raw materials decreases starch losses and minimizes waste production.

Lower Energy Requirements

Because enzymes facilitate tissue breakdown, less intensive mechanical processing may be required, reducing energy consumption.

Environmentally Friendly Process

Enzyme assisted extraction reduces the need for harsh chemicals and promotes sustainable processing practices.

Improved Economic Returns

Higher starch recovery and better product quality can increase profitability for starch-processing industries.

Applications in Cassava Starch Industry

Cassava is a major source of industrial starch in India. Conventional extraction methods often leave a considerable amount of starch in fibrous residues (thippi). Enzyme assisted extraction can significantly improve starch recovery from cassava tubers by degrading the pectin rich and cellulose rich cell wall matrix. The technology offers several benefits for cassava starch industries, including: Increased starch extraction efficiency, improved process sustainability, enhanced product quality, reduced starch losses in processing waste and better utilization of raw materials. These advantages make enzyme assisted extraction a promising technology for modern cassava starch processing industries.

Challenges and Future Perspectives

Despite its advantages, enzyme assisted starch extraction faces several challenges, including enzyme costs, optimization of processing conditions, and large scale industrial implementation. Future research should focus on developing cost effective enzyme formulations, improving enzyme stability, and integrating enzymatic treatment with existing starch extraction systems. Advances in biotechnology, enzyme engineering, and process optimization are expected to further enhance the commercial viability of enzyme assisted starch extraction.

Conclusion

Enzyme assisted starch extraction represents an efficient and sustainable technique for improving starch recovery from cassava and other starch rich root and tubers. By utilizing hydrolytic enzymes to degrade plant cell wall components, the technology facilitates greater release of starch granules, leading to higher yields, improved starch quality, and reduced processing losses. Its application in the cassava starch industry offers substantial economic and environmental benefits, making it a promising alternative to conventional extraction methods and a valuable tool for enhancing industrial starch production.

Cover story

From Biomass to Clean Water: How Biochar is Transforming Wastewater Treatment

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India is running out of clean water. The country holds barely 4% of the world's freshwater, yet nearly 70% of its surface water is too contaminated to drink. Over 163 million Indians have no access to safe drinking water, and roughly one in five communicable diseases here is directly tied to poor water quality. In global perspective, approximately 600 million people lack access to safe drinking water, hence achieving Sustainable Development Goal 6 (Ensure availability and sustainable management of water and sanitation for all by 2030) calls for rapid translation of recent research into practical and frugal solutions. Conventional treatment systems are expensive, energy-hungry, and out of reach for many communities. But an ancient material, biochar, now being reimagined by scientists, could change the calculus.

What is biochar?

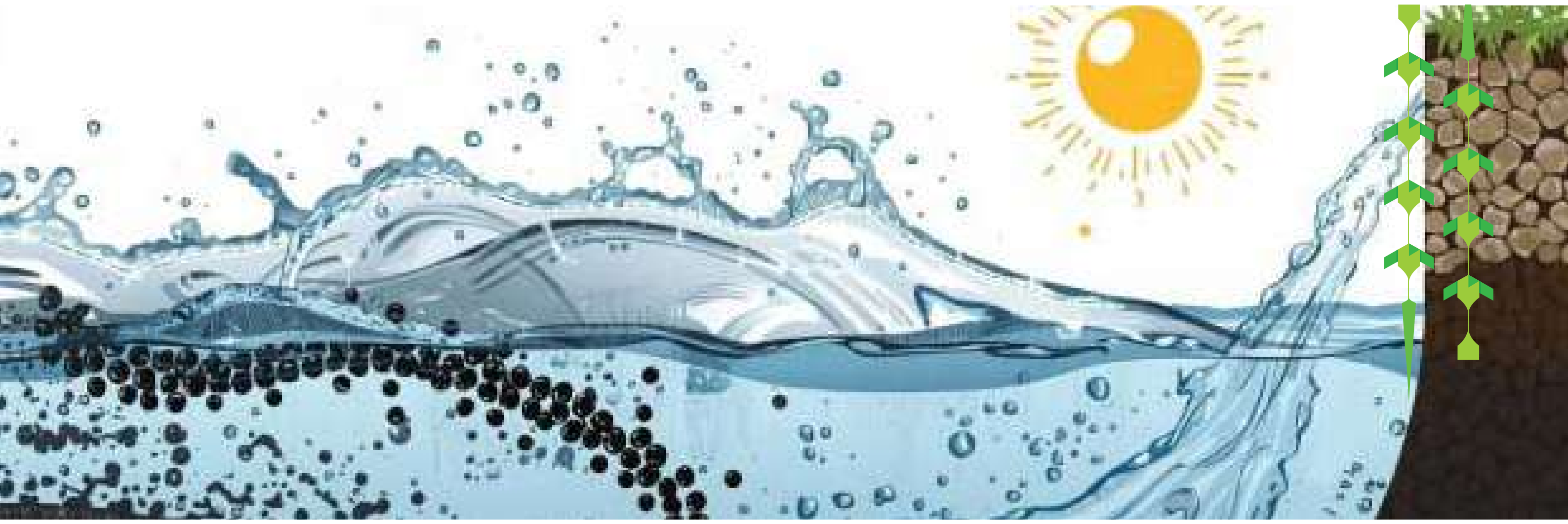
Biochar, popularly known as black carbon, is a highly porous carbonaceous material produced through the thermochemical decomposition of biomass under conditions of little or no oxygen. The material used for the production of biochar, generally referred to as the feedstock, can be any organic material. Biochar has immense potential for the removal of contaminants from aqueous solutions. Compared with conventional low-cost water treatment methods such as sand filtration, chlorination, and boiling, biochar-based water treatment offers promising and substantial improvements in water quality. In addition to its ability to remove physical, chemical, and biological contaminants, biochar preserves the organoleptic properties of water, including its taste, odour, and appearance.

Biochar

Production of biochar

Biochar can be produced from biomass by any thermochemical conversion processes, which are broadly classified into conventional and modern methods (Fig. 1). However, biochar is commonly produced by the process of ***pyrolysis***, where the organic compounds are broken down by applying heat in an oxygen-free environment, with temperatures ranging from 250–900 °C. The products of pyrolysis ***include biochar***, bio-oil, and syngas. Slow pyrolysis, also referred to as conventional pyrolysis, involves heating the biomass gradually at a rate of 5-7 °C per minute while simultaneously increasing the temperature within the range of 300-600 °C. Throughout the process of slow pyrolysis, there will be a notable increase in the production of oil and char. In fast pyrolysis, biomass is subjected to heating without oxygen at temperatures exceeding 500 °C and with a heating rate surpassing 300 °C per minute. This process typically produces 60-75% liquid products, 15-25% biochar, and 10-20% non-condensable gaseous products (Kwaku et al., 2023). Microwave pyrolysis and plasma pyrolysis are advanced pyrolysis techniques, used to produce high quality biochar. In open burning, biomass is combusted in open pit or under some kind of rudimentary structure, resulting in a product similar to charcoal. Among the modern methods of biochar production, gasification, hydrothermal carbonation, torrefaction are gaining importance.

Gasification functions at elevated temperatures ranging from 700°C to 1000°C and entails the partial oxidation of biomass. This process results in the production of a gas mixture known as syngas, as well as tar and biochar. ***Hydrothermal carbonization*** (HTC) is a method that removes water and carbon dioxide from fuel, increasing the fuel's carbon content and calorific value (Funke and Ziegler, 2010). Biomass with high moisture content is pre-treated within temperature of 180-250 °C and this pre-treated biomass can then be utilized in multiple ways.



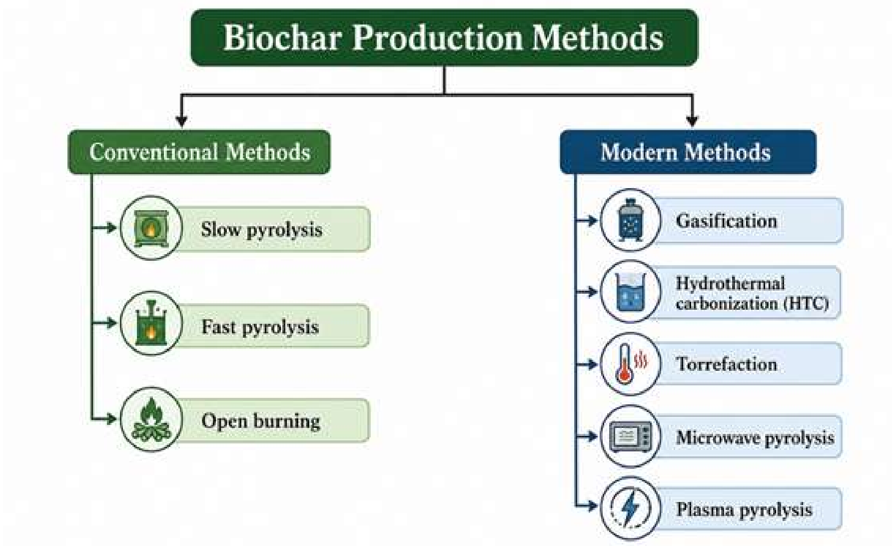


Fig.1: Methods of production of biochar

One relatively recent method for producing biochar is torrefaction. It heats at a low rate. Here, biomass is heated at temperatures ranging from 200 to 300°C .

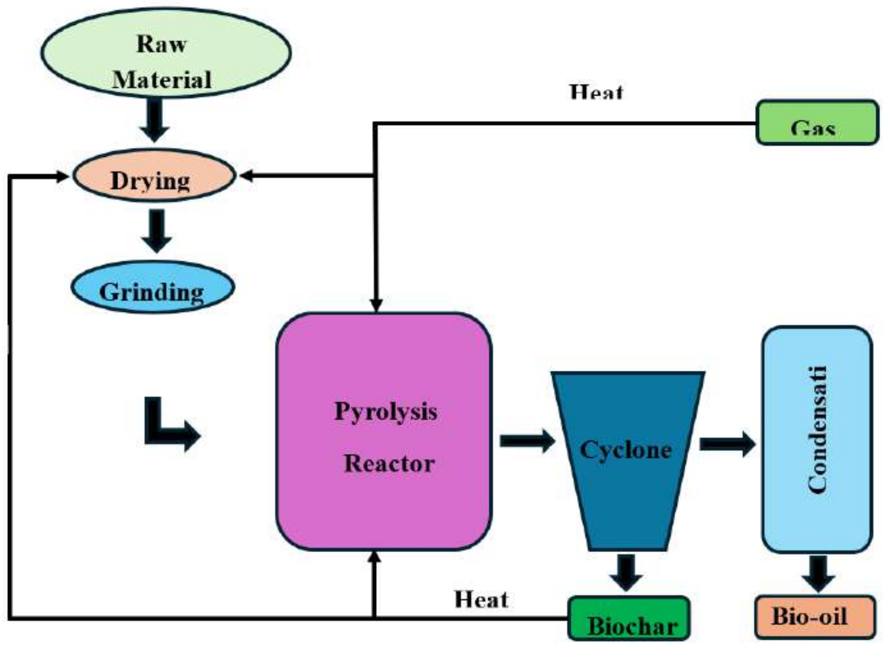


Fig. 2: Production of biochar by pyrolysis (Adapted from Khitab et al., 2021)

Properties of biochar

Characteristics of biochar is substantially influenced by the feedstock and the specific pyrolysis conditions. As a general rule, as the temperature used in the pyrolysis process rises, the resulting biochar will have a higher carbon content, energy value, porosity, and surface dimensions. At the same time, it will have a lower oxygen and hydrogen content and a lower bulk density.

Biochar is essentially a solid, high carbon, porous material with high surface area. A high temperature during pyrolysis promotes biochar production with a well-developed specific surface area, high porosity, pH, carbon and ash content, but low cation exchange capacity (CEC) and volatile matter content.

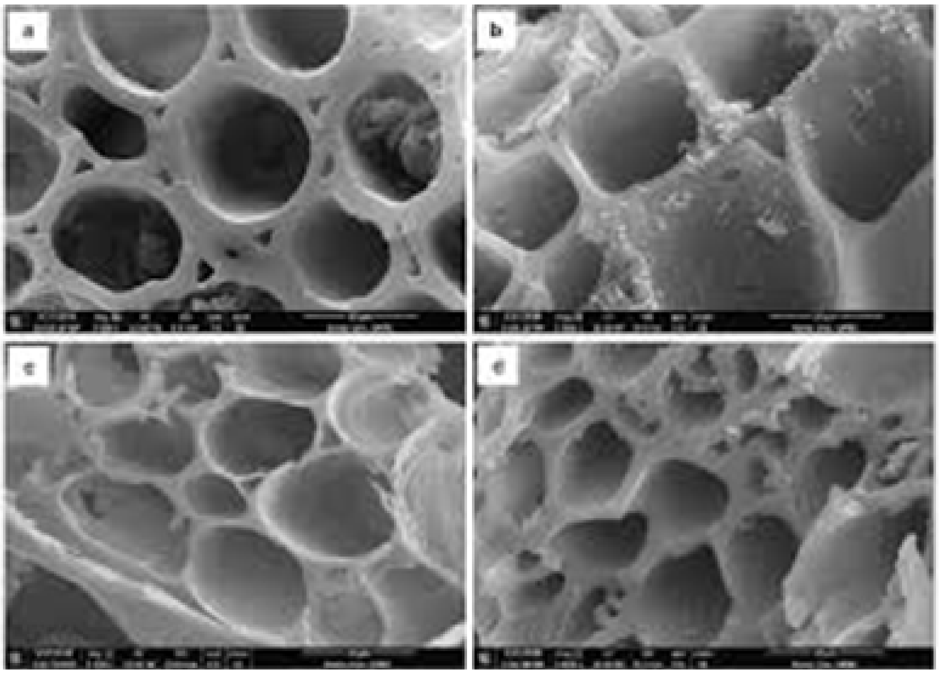


Fig. 3: SEM images of microporous structure of biochar

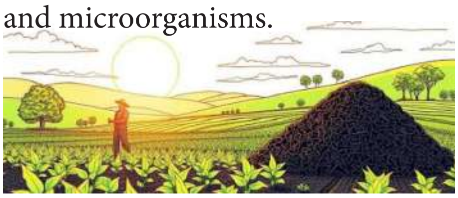
Role of biochar in wastewater purification

The properties of biochar vary widely according to the production conditions and feedstock used. Its pollution-fighting ability depends heavily on the feedstock used and the conditions under which it is made. Higher pyrolysis temperatures generally produce biochar with larger pores and greater surface area, both of which improve its capacity to capture contaminants.

But pore size matters in a more nuanced way too: biochar with very fine pores cannot physically trap larger pollutant molecules, regardless of their chemistry. This means biochar must be engineered thoughtfully matched to the specific contaminants in a given wastewater stream.

Sponge-like structure (as shown in Fig. 3) is what makes biochar remarkable as a water purifier. Heavy metals, organic pollutants, excess nutrients — biochar can trap them all through adsorption, ion exchange, and even supporting the microbial communities that break down contaminants biologically.

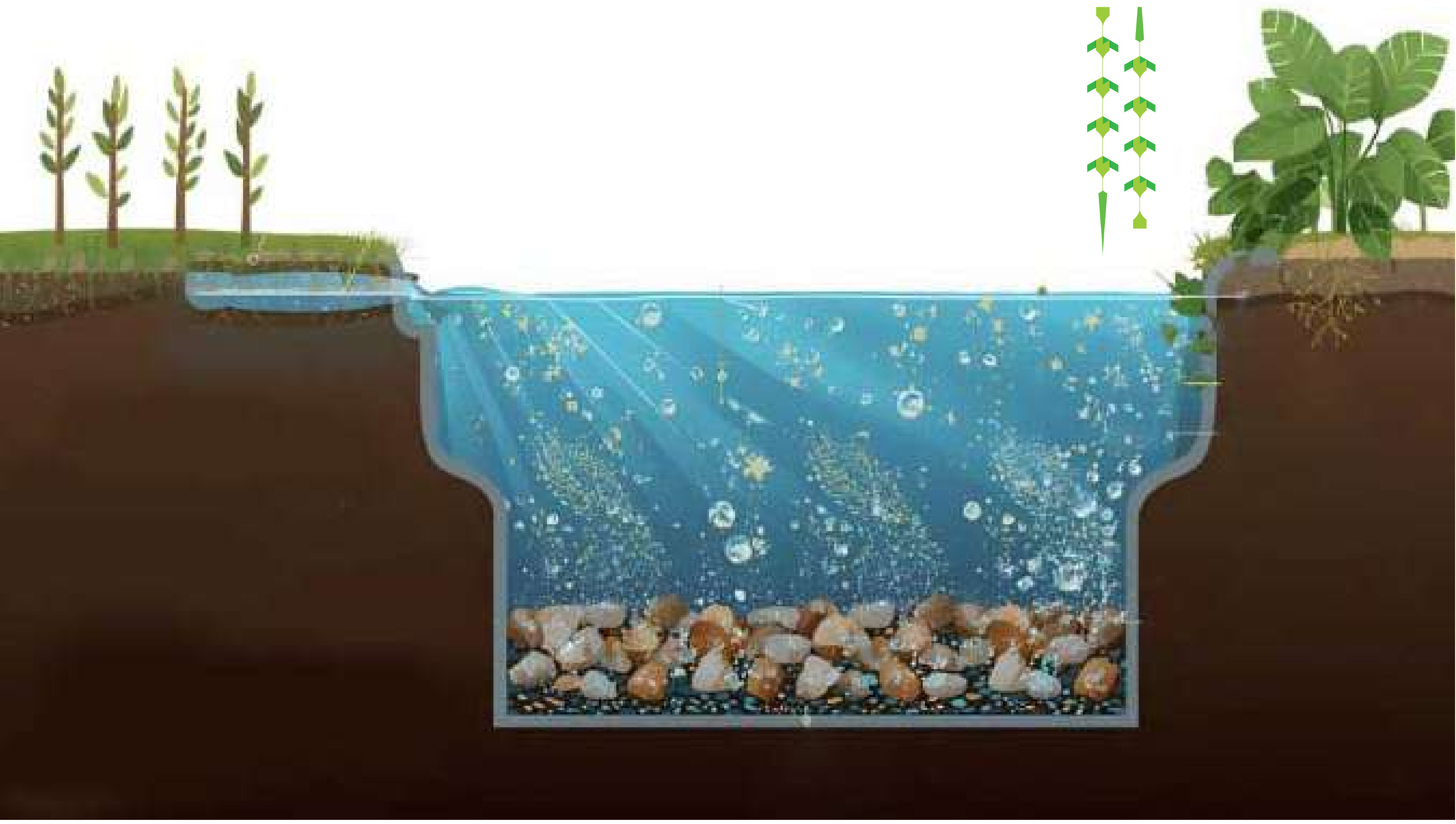
Biochar has demonstrated effectiveness in removing a broad spectrum of wastewater pollutants, including heavy metals, nutrients, organic pollutants, suspended solids and microorganisms.



Supercharging biochar

Researches are going further, modifying biochar to dramatically boost its performance. Physical activation using steam or carbon dioxide opens up the pore structure. Chemical activation — treating biochar with acids, alkalis, or oxidising agents — alters its surface chemistry to attract specific pollutants.

More recently, coating biochar with metal nanoparticles or metal oxides has shown promise, improving its ability to target contaminants with greater precision. Modified biochar is



being explored for removing arsenic, lead, phosphorus, and a range of agricultural chemicals from water, pollutants that plague rivers and groundwater.

The end-of-life question

Once biochar has done its job, what happens to it? This is a critical and often overlooked question, particularly when the material has absorbed toxic substances. Options being explored include using spent biochar as a soil amendment where its carbon content and porous structure can improve soil health; recycling it for another round of treatment, using it as a fuel source, or, in worst cases, controlled landfilling.

Conclusion

Biochar is an environmentally friendly, carbon-rich, porous material produced through the thermochemical conversion of biomass under limited or no oxygen conditions. Owing to its high specific surface area, well-developed pore structure, surface functional groups, and appreciable cation exchange capacity, biochar has emerged as a promising low-cost adsorbent for wastewater treatment.

Its physicochemical properties can be tailored by selecting appropriate feedstocks and production conditions, making it suitable for the removal of a wide range of contaminants from domestic, agricultural, and industrial wastewaters.

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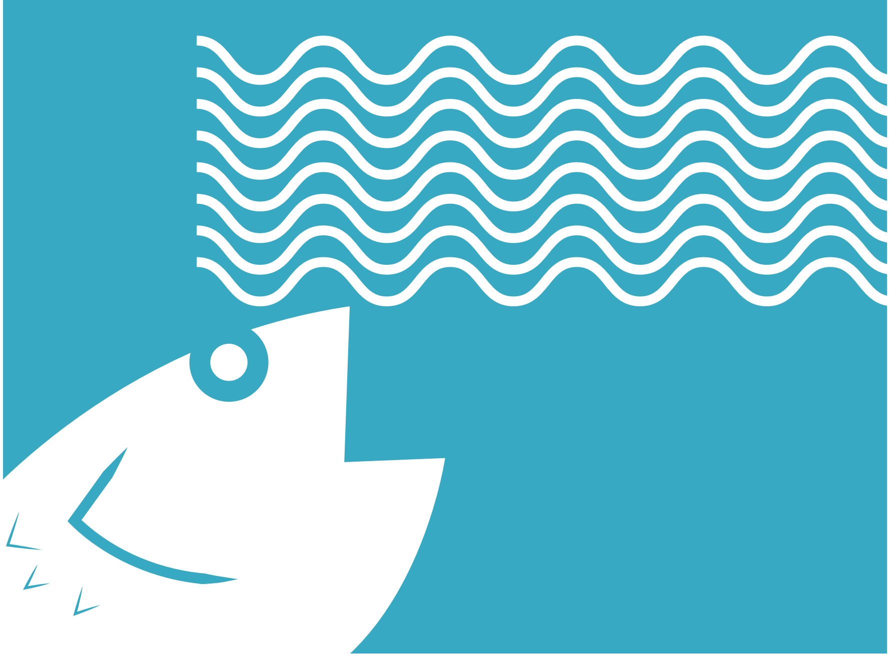

Pulsed Electric Field Technology: A Promising Approach for Fish Preservation

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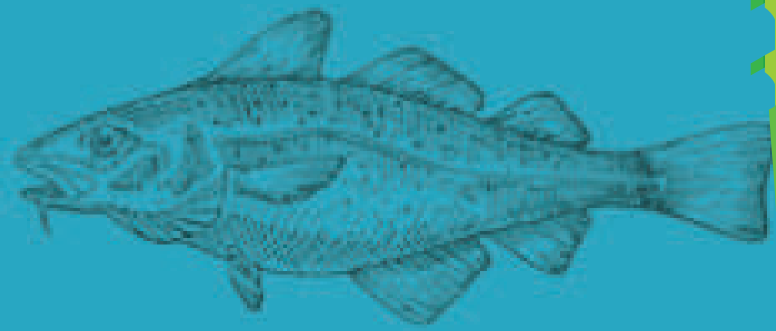
Introduction

Fish and fishery products are the most nutritious food due to the presence of essential fatty acids, vitamins, minerals and a source of high-quality animal protein for humans. On the other hand, fish is highly perishable because of the high moisture content, presence of unsaturated lipids, spoilage microorganisms, and enzymes (Kumar et al., 2024). Conventional preservation methods such as icing, freezing, drying, salting, smoking, and canning have been widely used for decades. However, these methods are effective in spoilage reduction often come with many drawbacks, including quality degradation, nutrient loss, undesirable changes in colour, texture, and flavour, high energy consumption, high cost and environmental impact etc. (Bashir et al., 2026). Furthermore, these conventional methods are not allied

PEF IN FISH PRESERVATION



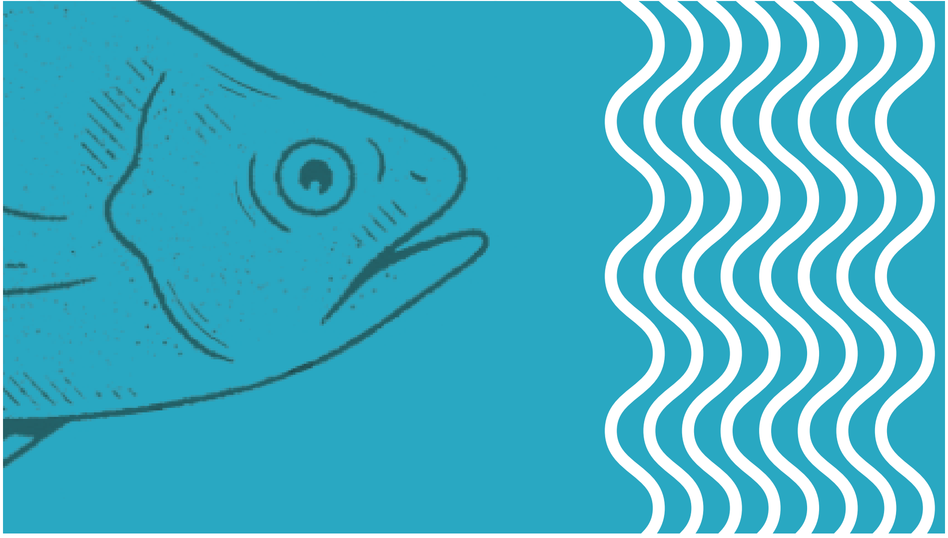
with consumer demands such as fresh-like, minimally processed food with nutritional integrity. In recent years, there has been growing interest in non-thermal technologies that can extend shelf life of foods while preserving the fresh-like quality and nutrients. One such non-thermal emerging technology is Pulsed Electric Field (PEF) treatment which can maintain nutritional and sensory qualities while enhancing safety and quality of fish and fishery products.

Pulsed Electric Field technology involves the application of short bursts of high-voltage electric fields to food placed between two electrodes. Unlike thermal processing, PEF does not rely on heat to inactivate microorganisms. Instead, it works by disrupting the cell membranes of microorganisms through a process known as electroporation. This leads to the leakage of intracellular components and ultimately results in microbial inactivation. Because the treatment is non-thermal and applied for only microseconds to milliseconds, the overall impact on the sensory and nutritional quality of fish is minimal.

Potential applications of PEF in Fish preservation

One of the most significant advantages of PEF in fish preservation is its ability to reduce microbial load without affecting the natural characteristics of the product. Studies have shown that PEF treatment can effectively inactivate spoilage bacteria and certain pathogens, thereby extending the shelf life of fresh and minimally processed fish. This is particularly beneficial for high-value seafood products where maintaining texture, color, and flavor is critical. Unlike conventional heat treatments, PEF preserves delicate compounds such as omega-3 fatty acids and prevents protein denaturation. PEF treatment preserves sensitive compounds, maintains the natural texture and color of foods, and reduces energy consumption (Bashir et al., 2026). Furthermore, PEF treatment can enhance the extraction yield of proteins, lipids, and bioactive compounds from marine biomass such as fish skin, bones, and viscera, etc. (Ahmed et al., 2025). This supports better utilization of processing waste and aligns with the growing emphasis on sustainability and resource efficiency in the seafood sector. In addition, PEF has been reported as a promising technology to improve water-holding capacity, tenderness, and texture of fish muscle (Guo et al., 2024).

Moreover, PEF has also shown potential as a pre-treatment method in fish processing operations. For instance, it can enhance mass transfer during drying by increasing cell



permeability, thereby reducing drying time and energy consumption (Liu et al., 2025). Similarly, in processes such as salting and marination, PEF can improve the penetration of salt and other additives, leading to more uniform product quality. These advantages make it an attractive option for improving process efficiency in the fish processing industry. A recent comprehensive review (Kumar et al., 2026) highlights that PEF is emerging as a viable green technology for producing safe, high-quality, and sustainable fish products with lower energy requirements.

Despite its advantages, the adoption of PEF technology in fish processing is still at a developing stage. High initial investment costs, the need for specialized equipment, and challenges in treating solid and thick tissues are some of the limitations that need to be addressed. In this regard, ICAR-CIFT has initiated the research work on the development of PEF system for fish and fishery products treatment which will make PEF more accessible and economically viable for fish preservation in the near future. The schematic representation of the PEF system which is aimed to be developed is shown in Fig. 1.

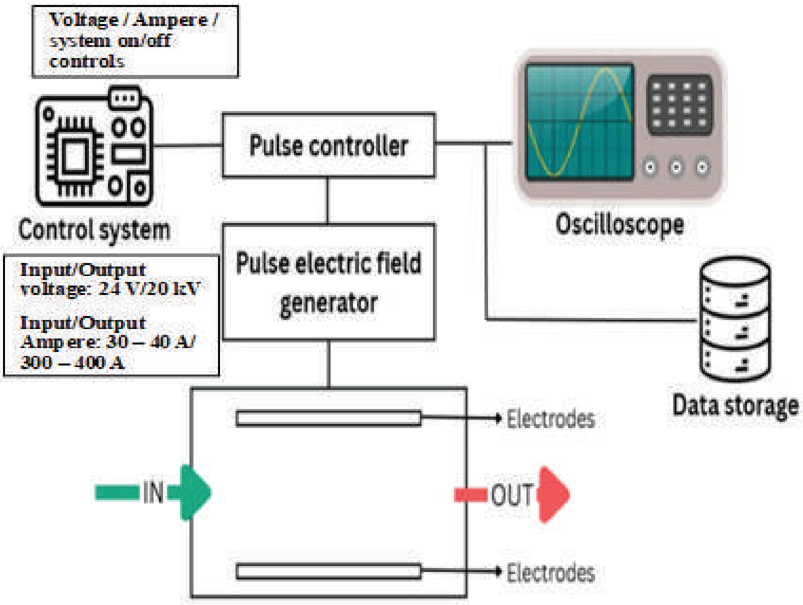
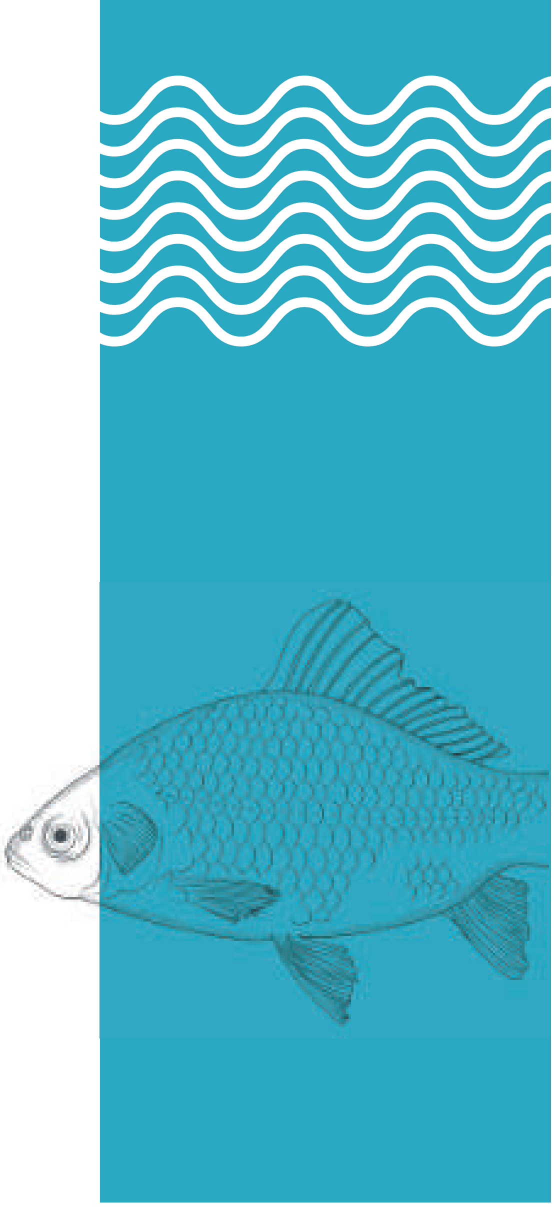


Fig. 1 Schematic of the components of PEF system



Conclusion

Pulsed Electric Field technology represents a promising, energy-efficient, and quality-preserving alternative to conventional fish preservation methods. Its ability to extend shelf life, maintain nutritional quality, and enhance processing efficiency makes it particularly suitable for modern seafood processing systems. As the industry moves towards sustainable and high-quality food production, PEF is likely to play an increasingly important role in shaping the future of fish preservation. Its wider adoption could enhance food safety and quality while supporting circular bioeconomy practices and reducing environmental impact.

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Crop Diversity

From Black Turmeric to Mango Ginger: Exploring the Curcuma Family

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When we think of turmeric, the familiar golden-yellow rhizome of Curcuma longa usually comes to mind. However, the turmeric family is far more diverse than most people realize. The genus Curcuma (Family Zingiberaceae) comprises more than 120 species of perennial rhizomatous herbs, many of which are native to the tropical and subtropical regions of Asia. India is one of the world's richest centres of Curcuma diversity, harbouring a remarkable array of species that have been treasured for centuries as spices, medicines, cosmetics, natural dyes, starch sources and ornamental plants.

While these species share a common rhizomatous growth habit, each possesses unique morphological features that distinguish it from the others. Differences in leaf shape and colour, inflorescence characteristics, rhizome colour, aroma, and texture not only aid in species identification but also reflect their diverse adaptations and uses. Among the numerous species found in India, Curcuma longa (commercial turmeric), C. aromatica (wild turmeric), C. amada (mango ginger), C. caesia (black turmeric), C. zedoaria (white turmeric or zedoary), and C. angustifolia (East Indian arrowroot) are of outstanding economic importance. Each of these species has evolved distinctive

characteristics that make it valuable for specific culinary, medicinal, pharmaceutical, cosmetic or industrial applications.

1. Curcuma longa (Commercial Turmeric)

Curcuma longa is the most widely cultivated and economically important species of the genus Curcuma. It is the principal commercial source of turmeric, valued globally as a spice, natural food colourant, preservative and medicinal plant. Its rhizomes are rich in curcuminoids, particularly curcumin, which imparts the characteristic golden-yellow colour and confers antioxidant and anti-inflammatory properties.

Morphologically, C. longa is a robust perennial herb, 80–120 cm tall, with a compact pseudostem formed by overlapping leaf sheaths. The leaves are large, glabrous, oblong-lanceolate to elliptic, with an acuminate apex, entire margins and a uniformly green midrib lacking pigmentation. The terminal inflorescence is a compact spike (10–20 cm long) bearing pale green fertile bracts and white to pale green coma bracts, occasionally tinged pink. The flowers are pale yellow to yellowish-white with a trilobed labellum. Most cultivated forms are sterile triploids propagated vegetatively through rhizomes. The rhizome system comprises a thick ovoid mother rhizome with numerous cylindrical primary and secondary finger rhizomes. The rhizomes are externally yellowish-brown and internally bright orange-yellow due to their high curcuminoid content. Their smooth surface, distinct annular leaf scars, pleasant aroma and deep orange-yellow flesh are the principal diagnostic features of C. longa.

Diagnostic features: Bright orange-yellow curcumin-rich rhizomes, uniformly green glabrous leaves without a purple midrib and white to pale green coma bracts.

2. Curcuma aromatica (Kasthuri Turmeric/ Wild Turmeric)

Curcuma aromatica is an economically important species valued primarily for its medicinal, cosmetic and aromatic properties. Unlike C. longa, it is seldom used as a culinary spice because of its low curcumin content and characteristic camphoraceous aroma. Its rhizomes are extensively utilized in herbal cosmetics, including face packs, soaps, skin-care products and Ayurvedic formulations.

Morphologically, C. aromatica is a perennial herb growing 60–90 cm tall. It produces a compact pseudostem with broad elliptic to ovate, bright green leaves .The leaf upper surface is glabrous, whereas the lower surface is densely pubescent with a velvety texture, distinguishing it readily from C. longa. Flowering usually occurs before leaf emergence, producing a short lateral spike from the rhizome. The inflorescence comprises green fertile bracts with conspicuous pink to purplish coma bracts enclosing pale yellow, fragrant flowers. The rhizome system consists of a small central mother rhizome with numerous slender finger rhizomes. The rhizomes are light brown externally and creamy white to pale yellow internally, lacking the deep orange pigmentation of commercial turmeric. They possess a strong camphor-like aroma due to their high essential oil content and contain relatively low concentrations of curcuminoids.

Diagnostic features: Creamy white aromatic rhizomes with a camphoraceous smell, broad leaves with or without a reddish-purple midrib, densely hairy lower leaf surface, and pink to purplish coma bracts appearing before leaf emergence.

3. Curcuma zedoaria (Zedoary/ Manja Koova)

Curcuma zedoaria is an economically important medicinal species widely used in Ayurveda, cosmetics, perfumery and as a natural dye. Its rhizomes are rich in essential oils and are traditionally used as digestive, carminative and anti-inflammatory agents. Unlike C. longa, it has low curcuminoid content and is valued primarily for its aromatic and medicinal properties.
Morphologically, C. zedoaria is a robust perennial herb reaching 1.2–1.5 m in height. It bears a stout pseudostem with large oblong-lanceolate leaves, typically marked by a conspicuous purplish-red or brown band along the upper surface of the midrib. The lower leaf surface is pubescent,

providing a useful diagnostic character. Flowering occurs before or concurrently with leaf emergence, producing a lateral spike directly from the rhizome. The inflorescence consists of green fertile bracts surmounted by pink to crimson-purple coma bracts enclosing pale yellow to whitish flowers.The rhizome system is large, thick, irregularly branched, and highly fibrous. Rhizomes are pale brown to greyish-brown externally and cream to sulphur-yellow internally. They have a bitter taste and a spicy ginger-like aroma. Compared with C. longa, the rhizomes contain substantially lower concentrations of curcuminoids but are rich in essential oils, which account for their medicinal and aromatic value.

Diagnostic features: Large pubescent leaves with a purplish-red midrib, robust early-flowering inflorescence with pink to crimson coma bracts, and large cream to yellow-orange fibrous rhizomes having a bitter, aromatic flavour.

4. Curcuma amada (Mango Ginger)

Curcuma amada (Mango Ginger) is an economically important species cultivated for its aromatic rhizomes, which possess the characteristic flavour and aroma of raw mango. Owing to its very low curcumin content, it is used mainly in pickles, chutneys, salads and other culinary preparations rather than as a spice. The rhizomes are also valued in Ayurveda for their digestive and carminative properties.

Morphologically, C. amada is an erect perennial herb growing 0.8–1.2 m tall. It develops a slender pseudostem bearing large oblong-lanceolate to lanceolate, bright green, glabrous leaves that lack the purple midrib band characteristic of several other Curcuma species. Both the leaves and fresh rhizomes emit a distinctive raw mango aroma when crushed, serving as a key diagnostic feature. The inflorescence arises either centrally among the leafy shoots or separately on a short peduncle and consists of green fertile bracts with pale pink to white coma bracts enclosing pale yellow to creamy-white flowers.The rhizome system comprises a central mother rhizome with smooth, elongated cylindrical finger rhizomes that are less branched and softer than those of C. longa. Rhizomes are cream to light brown externally and creamy white to pale yellow internally, reflecting their low curcuminoid content. They are tender, low in fibre, and highly aromatic, making them well suited for fresh consumption and processing.

Diagnostic features: Bright green glabrous leaves without a coloured midrib, creamy white to pale yellow rhizomes with a characteristic raw mango aroma, pale pink to white coma bracts and soft, low-fibre rhizomes used extensively for pickles and chutneys.

5. Curcuma angustifolia (East Indian Arrowroot)

Curcuma angustifolia is an economically important species cultivated for its starch-rich rhizomes. The highly digestible starch is widely used as a substitute for true arrowroot in infant foods, therapeutic diets, confectionery, and traditional food preparations. Unlike C. longa, it contains negligible amounts of curcumin and is valued primarily for its edible starch.

Morphologically, C. angustifolia is a slender, erect perennial herb growing 60–100 cm tall. It produces a narrow pseudostem with linear- to lanceolate, bright green, glabrous leaves that lack the coloured midrib band found in several other Curcuma species. The narrow leaves are a key diagnostic feature. Flowering generally precedes leaf emergence, producing a compact lateral spike with green fertile bracts and white to pale pink (occasionally bright pink) coma bracts enclosing white to pale yellow flowers.The rhizome system consists of small, globose to elongated cylindrical rhizomes that are moderately branched and relatively smooth. Rhizomes are pale brown externally and white to creamy white internally, with a high starch content and low fibre. The absence of yellow-orange pigmentation reflects the negligible accumulation of curcuminoids. These smooth, starch-rich rhizomes are harvested for the production of premium-quality arrowroot flour.

Diagnostic features: Very narrow glabrous leaves, white starchy rhizomes with negligible curcumin, early flowering with white to pink coma bracts and rhizomes cultivated exclusively for high-quality arrowroot starch.

6. Curcuma caesia (Black Turmeric/Black Zedoary)

Curcuma caesia (Black Turmeric, Black Zedoary, Blue Zedoary or Kali Haldi) is one of the most distinctive and medicinally important species of the genus Curcuma. It is widely used in Ayurveda and traditional medicine, particularly in eastern India and parts of Kerala, for its anti-inflammatory, antimicrobial and analgesic properties. Its rhizomes are valued for their high essential oil content rather than curcuminoids.

Morphologically, C. caesia is an erect perennial herb growing 70–100 cm tall. It produces a compact pseudostem with broad elliptic to lanceolate, deep green and bluish green in under surface, glabrous leaves. Flowering occurs before or during early leaf emergence, producing a lateral spike with green fertile bracts, deep pink to reddish-violet coma bracts, and pale yellow to pale pink flowers with a yellow-orange labellum. The rhizome system is compact, consisting of small, irregularly branched rhizomes with few finger rhizomes. Rhizomes are dark brown externally and characteristically bluish-black to deep violet internally, making them unique among cultivated Curcuma species. They possess a strong camphoraceous aroma and spicy flavour due to their high essential oil content, which readily distinguishes them from other economically important species.

Diagnostic features: Bluish-black rhizomes, with or without deep purple midrib on broad glabrous leaves, deep pink to reddish-violet coma bracts and a strong camphoraceous aroma.

7. Curcuma pseudomontana (Hill Turmeric)

Curcuma pseudomontana is a wild species native to the Western Ghats and other hilly regions of India. Although not cultivated commercially, it is an important medicinal plant and a valuable genetic resource for germplasm conservation and Curcuma breeding because of its wide ecological adaptation and genetic diversity.

Morphologically, C. pseudomontana is an erect perennial herb growing 60–75 cm tall. It produces slender pseudostems bearing oblong to lanceolate, glabrous leaves with a sharply acuminate apex. The leaves are dark green above, pale green beneath, and lack the purple midrib band found in several other Curcuma species. The inflorescence emerges separately from the leafy shoot before or during leaf emergence and consists of green fertile bracts with bright pink coma bracts enclosing pale yellow flowers. The rhizome system comprises small, aromatic mother rhizomes with few short finger rhizomes. Rhizomes are pale brown externally and pale cream to yellowish internally. They are smaller and less branched than those of C. longa and possess a characteristic aromatic fragrance. Although not commercially exploited, the species is valued for its medicinal properties and as a source of useful genes for crop improvement.

Diagnostic features: Short stature, glabrous dark green leaves without a coloured midrib, bright pink terminal coma bracts and small aromatic pale cream to yellow rhizomes.

Curcuma longa

Curcuma aromatica

Curcuma angustifolia

Curcuma caesia

Curcuma zedoaria

Curcuma amada

Curcuma pseudomontana

Curcuma longa

Curcuma aromatica

Curcuma angustifolia

Curcuma caesia

Curcuma zedoaria

Curcuma amada

Curcuma pseudomontana

Curcuma longa

Curcuma aromatica

Curcuma angustifolia

Curcuma caesia

Curcuma zedoaria

Curcuma amada

Curcuma pseudomontana

Corn Silk: Nutritional Composition, Nutraceutical Potential and Value-Added Applications

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INTRODUCTION

India is the world's fifth-largest producer of maize (corn), with a record output of over 43 million metric tonnes. Primarily grown during the monsoon season, it serves as a crucial raw material for animal feed, poultry, and industrial starch, in addition to direct food consumption. Over 60% of domestic corn is used for poultry and livestock feed. The industrial sector (starch, sweeteners, and ethanol) consumes around 20-25%. Corn silk is the long, fine, thread like fibers that emerge from the female flower of the maize plant (zea mays L). These strands extend from the ear of corn and play a crucial role in plant reproduction by capturing pollen grains during fertilization. Traditionally discarded as an agricultural waste, corn silk has gained significant attention in recent years to its nutraceutical potential. Nutraceutical are food derived substances that provide health benefits beyond basic nutrition, including disease prevention and health promotion. Corn silk contains a wide range of bioactive compounds that make it an important functional food ingredients. Corn silk, also known as stigmata maydis is a valuable by-product of corn processing. In India, corn is a widely cultivated crop and its silk is often considered waste. However, corn silk has various uses and its utilization can provide additional income to farmers and processors.

Although corn silk has been employed in traditional medicine for centuries, systematic scientific exploration of its pharmacological properties has only recently commenced. The growing emphasis on phyto-therapeutics and functional foods has positioned corn silk as a promising multifunctional botanical worthy of rigorous investigation. The emergence and growth of silk generally occur between 55 and 75 days after sowing, with silk elongation playing a key role in successful pollination. Morphological traits such as silk length and density vary across genotypes, influencing both yield potential and quality outcomes. Environmental stresses, including drought, elevated temperatures, and nutrient deficiencies, can hinder silk emergence or accelerate desiccation, thereby compromising fertilization success and reducing recoverable biomass.

According to recent estimates, silk accounts for approximately 3.5% of the total cob weight, and the average recovery is about 7.5 kg per 1000 kg of green corn. In India, with annual green corn production exceeding 25 million tonnes, the potential recoverable corn silk biomass is estimated at over 0.9 to 1.1 million tonnes per year, much of which remains underutilized. This represents a significant resource for value-added processing in food, pharmaceutical, and cosmeceutical sectors.

Corn silk is relatively easy to collect as it is manually or mechanically separated during post-harvest cob stripping. The low cost of collection and the absence of competing food use make it a suitable candidate for circular bioeconomy models. Integrating corn silk utilization into agro-industrial chains could enhance farmer income, reduce waste, and support sustainable resource management.

Functional and Nutritional Properties of Corn Silk

Corn silk demonstrates diverse functional properties that support its integration into a wide range of food products and nutraceutical formulations. Its interactions with water, oil, and other food constituents enhance its utility as a functional ingredient, particularly in fiber-enriched, low-fat, and moisture-retentive applications.

Corn silk possesses a distinctive nutritional profile that makes it valuable for use in functional food and nutraceutical applications. The fresh corn silk taken from baby corn has 92.49 % of moisture. Dried corn silk typically contains 4.0% to 7.0% moisture, depending on the stage of harvest and drying methods used. A low moisture level enhances storage potential and reduces the risk of microbial spoilage in powdered formulations.

Table 1: Nutritional compositions (%, dry basis) of immature and mature corn silk

Nutritional compound	Corn silk	
	Immature silks	Matures silks
Moisture (fresh)	89.31	84.42
Moisture (oven dried)	4.15	3.90
Crude lipid	1.27	0.66
Crude protein	12.96	8.95
Ash (%)	5.28	5.51
Carbhohydrate	27.80	29.74
Total dietary fiber (g/100g)	48.50	51.24

Corn silk contains a relatively high protein content, reported between 12.0% and 17.0% on a dry weight basis, positioning it as a notable source of plant-derived protein among floral agricultural residues. Beyond its nutritional role, the protein fraction may contribute to bioactive properties, lending support to the therapeutic potential attributed to corn silk. In contrast, its total fat content is typically low, ranging from 0.5% to 1.2%; yet, this fraction includes valuable lipids such as phytosterols and tocopherols, known for their cardiovascular and antioxidant benefits. The naturally low-fat profile enhances its compatibility with dietary strategies aimed at reducing fat intake.

Corn silk contains an ash fraction ranging from 6.0% to 10.0%, reflecting its richness in mineral elements such as calcium, potassium, magnesium, and phosphorus. Elevated ash values correspond to greater mineral availability, underscoring its nutraceutical potential. Carbohydrates, which constitute the major portion of corn silk dry matter (27.0%–56.0%), are primarily complex polysaccharides including cellulose, hemicellulose, lignin, pectin, and glucan. Dietary fiber, comprising both soluble and insoluble components, is a major nutritional attribute of corn silk and contributes to its physiological and functional relevance in health management. The total fiber content in corn silk ranges broadly depending on the plant's maturity and variety, with reported values between 14.8 and 53.3 g/100 g on a dry weight basis. Specifically, immature corn silk has been shown to contain approximately 49.5 g/100 g, while mature corn silk may contain even higher levels at 53.3 g/100 g.

Pharmacological Insights and Therapeutic Applications

Diuretic and Kidney Protective Benefits: Corn silk has long been valued in traditional medicine as a natural diuretic, and modern research supports its ability to enhance urinary output and promote kidney health. Evidence suggests that corn silk extract can reduce calcium accumulation in renal tissue, improve blood urea nitrogen and serum creatinine levels, and inhibit calcium oxalate deposits, thereby minimizing the risk of kidney stone formation. Its nephroprotective effects are further linked to the suppression of lipid peroxidation and the activation of antioxidant enzymes in the kidneys, offering protection against oxidative stress and renal damage.

Antidiabetic Potential: Corn silk demonstrates notable antidiabetic activity, primarily by inhibiting the enzymes α-amylase and α-glucosidase, which slow carbohydrate digestion and help reduce postprandial glucose surges. In diabetic mouse models, corn silk extract effectively lowered blood glucose levels by enhancing insulin secretion and protecting pancreatic β-cell function. Among its bioactive fractions, the ethyl acetate and butanol extracts showed strong antioxidant capacity and glucose-lowering effects, highlighting their therapeutic relevance in controlling hyperglycemia and preventing diabetic nephropathy.

Antioxidant and Anti-inflammatory Properties: Corn silk is widely recognized for its strong antioxidant activity, largely due to its abundance of polyphenols, including flavonoids such as maysin and luteolin. These compounds effectively neutralize reactive oxygen species (ROS) and inhibit lipid peroxidation, thereby safeguarding tissues against oxidative stress. In experimental models of inflammation, corn silk extract significantly reduced inflammatory mediators and curtailed leukocyte migration during acute inflammatory responses, underscoring its potent anti-inflammatory potential.

Antihypertensive and Cardiovascular Benefits: Corn silk has shown hepatoprotective effects in experimental models by reducing liver enzyme levels and improving histopathological outcomes. These benefits are attributed to its antioxidant potential, which reduces oxidative stress and inflammation in hepatic tissue. Supplementation with corn silk extract improved liver morphology and restored antioxidant enzyme activities, further indicating its hepatoprotective utility.

Antiobesity Potential: The weight-management benefits of corn silk are primarily linked to its ability to inhibit adipogenesis, the process of fat cell formation. In animal studies, supplementation of a high-fat diet with corn silk resulted in reduced body weight, lower fat mass, and improved serum lipid profiles. These findings highlight corn silk's promise as a natural agent for combating obesity and related metabolic disorders.

Anticancer Potential: Corn silk shows promise in fighting cancer through several mechanisms, including antioxidant protection, triggering cell death (apoptosis), and blocking cancer cell growth. The flavonoid maysin has been found to activate caspase pathways and damage cancer cell mitochondria, leading to apoptosis in liver and colon cancer cells. In addition, corn silk polysaccharides boost immune function, further strengthening its anticancer effects.

Utilisation of Corn Silk

Once regarded as agricultural waste, corn silk has emerged as a valuable resource owing to its rich nutritional and phytochemical composition. Its incorporation into food and nutraceutical sectors is gaining momentum, particularly within the food industry where its abundance of dietary fiber, flavonoids, polyphenols, and other antioxidants has enabled successful integration into diverse product formulations. Corn silk powder has been effectively utilized in bakery formulations such as crackers and yeast breads, enhancing nutritional and functional qualities. Beyond baked goods, corn silk is widely incorporated into herbal teas and functional beverages, with corn silk tea itself undergoing clinical evaluation and demonstrating promising antihypertensive effects. Fermented products including corn silk wine and vinegar, have also been developed, enriched with bioactive volatiles that exhibit antioxidant and antimicrobial properties, thereby strengthening their appeal as health-promoting functional beverages. Additionally, Indian traditional foods like chapatti, parantha, ladoo, raita and dal have been enriched with corn silk in the range of 5 to 10 per cent, significantly increasing their fiber and mineral content and making them functional foods with therapeutic benefits.

Conclusion: Corn silk, often considered agricultural waste, is in fact a rich source of therapeutic compounds with wide-ranging health benefits. Its incorporation into the food industry holds great promise, as it can be processed into diverse products such as biscuits, crackers, bread, beverages (both alcoholic and non-alcoholic), patties, meatballs, and traditional foods like chapathi, parantha, dal, and ladoo. This review emphasizes the nutritional composition of various corn varieties, the pharmacological activities of bioactive compounds present in corn silk, and its potential applications. Such insights pave the way for its integration into value-added and nutraceutical food products, transforming waste into wellness.

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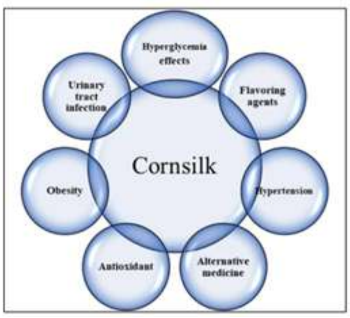
Corn silk fibers

Stages of corn silk



Health benefits of corn silk

Okra
The Versatile Star Vegetable

By Dr. Pallot Sindhumole

Okra (Abelmoschus esculentus L.), popularly known as lady's finger or bhindi or venta, is much more than a common kitchen vegetable. Packed with essential nutrients and unique bioactive compounds, it has earned recognition as a "superfood" with remarkable health benefits. Beyond its nutritional value, okra also finds applications in cosmetics, food processing, eco-friendly packaging, and even arts and crafts, making it a truly versatile vegetable.

A Nutritional Powerhouse

Okra is an excellent source of a wide range of nutrients, supporting the overall health.
It contains significant amount of:

- **Vitamins - A, C, K, B6**
- **Minerals - Calcium, Iron, Magnesium, Potassium, Iodine**
- **Antioxidants**
- **Pectin**
- **Lectin**
- **Polyphenols**

The superb, most distinctive, component of okra is its mucilage—a natural gel-like substance that is rich in soluble dietary fibre. This unique characteristic contributes to many of its health-promoting properties and industrial applications.

Health Benefits of Okra

Regular consumption of okra can contribute to better health in several ways:

•Supports Eye Health

Being rich in vitamin A and antioxidants, okra helps maintain healthy vision and protects the eyes from oxidative damage.

•Helps to Manage Cholesterol

The soluble fibre present in okra helps to reduce cholesterol absorption, supporting healthy cholesterol levels.

•Promotes Heart Health

By helping in the regulation of cholesterol, improving blood circulation, and providing antioxidant protection, okra contributes to cardiovascular well-being.

•Improves Blood Circulation

Essential minerals such as iron and magnesium support in healthy blood formation as well as its circulation throughout the body.

•Reduces Oxidative Stress

The antioxidants and polyphenols in okra help to neutralise harmful free radicals, reducing oxidative stress and protecting cells from damage.

•Supports Healthy Blood Sugar Levels

The soluble fibre and mucilage may help to slow down glucose absorption, contributing to better blood sugar management.

•Enhances Digestion

Okra's high fibre content promotes healthy digestion, supports beneficial gut bacteria, and helps to maintain regular bowel movements.

•Reduces Inflammation

Natural antioxidants and bioactive compounds present in okra may help to reduce inflammation and promote overall wellness.

Ways to include Okra in your diet

Okra is highly versatile and can be enjoyed in several forms:
•Raw in salads
•Fried
•Boiled
•Cooked in curries and stews
•As okra-infused water
Fresh okra generally retains higher levels of vitamins, minerals, and amino acids than boiled or overprocessed okra. It can also be dried and powdered. Incorporating about 5% okra powder into snacks enhances their nutritional value while maintaining acceptable flavour and texture.

Okra-Infused Water

Okra water is a refreshing and nutritious alternative to plain drinking water. It is prepared by slicing tender okra pods and soaking them overnight in clean water. During soaking, the mucilage and valuable nutrients are

released into the water, giving it a slightly thick, slippery texture and a mild, neutral taste. It can be consumed as it is or served chilled.

Beyond Food: The Non-traditional uses of Okra

Creative Craft Material

Fresh okra pods can be cut crosswise to create attractive floral patterns for paper printing, fabric painting, greeting cards, and other craft projects. Dried pods are also used to make decorative wall art, ornaments, wreaths and driftwood arrangements.

Natural Cosmetic Ingredient

Okra mucilage serves as an excellent natural moisturiser for the skin. In hair care, it acts as a natural conditioner and detangler, leaving hair soft, manageable, and shiny.

Biodegradable Packaging Material

When combined with natural polymers such as starch or cellulose, okra mucilage can be used to develop biodegradable packaging materials, offering a sustainable alternative to synthetic plastics.

Valuable Ingredient in Food Industry

Okra mucilage has gained considerable attention as a natural food hydrocolloid because it is biodegradable, biocompatible, non-toxic, and environment-friendly. Its functional properties make it suitable for numerous food applications such as:

Thickener, Gelling Agent, and Stabilizer

Okra mucilage is widely used to improve the texture and stability of soups, sauces, and various food formulations. It has also shown great promise as a natural emulsifier and stabilizer in coconut milk and other emulsified products.

Healthy Replacer of Fat

Okra mucilage can successfully replace a portion of fat in products such as chocolate bar cookies, helping reduce fat content while maintaining desirable texture and quality.

Alternative for Egg White

As a whipping agent, okra mucilage can replace uncooked egg whites in cake preparation. It improves batter volume and contributes to better texture, making it a promising ingredient for plant-based and allergen-friendly baking.

Food Stabilizer

Research has demonstrated the effectiveness of okra mucilage as a stabilizer in pistachio nut paste. Its addition increased product stability from approximately 80.8% in the control sample to over 97%, highlighting its potential as a valuable natural food additive.

Conclusion:

Whether consumed fresh, prepared as okra water, incorporated into food products, or used in innovative industrial applications, okra truly deserves its reputation as a multifaceted star vegetable. As consumer demand grows for natural, sustainable, and health-promoting ingredients, okra continues to attract interest from researchers and the food industry alike. Its exceptional nutritional profile, functional properties, and environment-friendly applications make it one of the most promising vegetables for future food innovations.

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Makhana Magic:
Why This Ancient Superfood Is Taking Over Modern Snack Shelves?

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Introduction

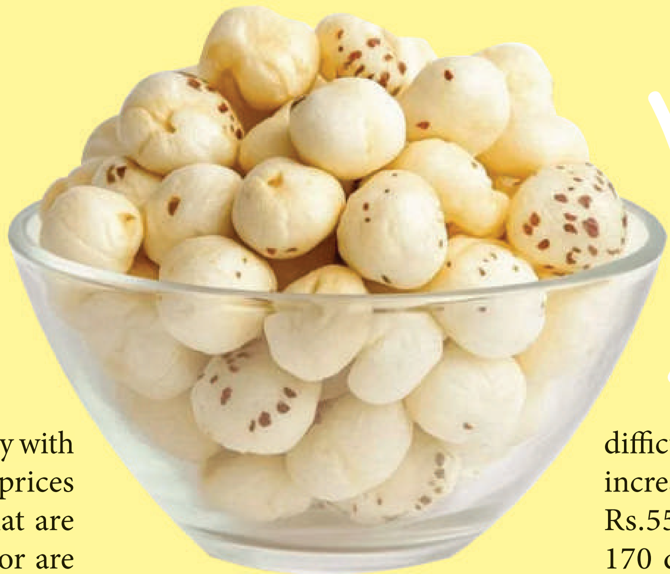
most widely used edible seed in Indian cuisine, 'Makhana' is the seed of a water lily plant botanically known as 'Euryale ferox' and belongs to the family 'Nymphaceae. ' The aquatic plant has a purple flower at the top of the prickly red stalk, which resembles a small lotus, as the flattened gigantic round leaves float on the muddy ponds of perennial water bodies in which it is cultivated. Nowadays, there is a high demand for popped seeds of Makhana called 'Fox nuts' or 'Gorgon nuts'. It is considered an alternative to popcorn, and is commercially cultivated in many areas as a high-value commodity. Owing to increasing health awareness among people, super food or black diamond 'makhana' is consumed globally as a healthy low-calorie and sugar-free food in curries and evening snacks. India accounts for almost three-fourths of world makhana production, and Bihar's contribution is approximately 90% of the total production in India.

Method of Cultivation

Makhana is cultivated in water bodies of 1-2 m depth (Figure 2). and water bodies that are in cultivation do not require saplings, as the leftover seeds automatically grow as saplings (Kumar et al., 2020). The plant requires heavy rains to bear fruit during spring. In summer, the fruits start to rot, which causes the black-colored seeds to float on the surface of the water. In the summer season, owing to high heat, the seeds sink and get trapped in the bottom soil where they rest for a month. Each plant contains six fruits (Figure 4). ,which gave a yield of 70–125 seeds/plant.

Harvesting

Growers sweep the bottom surface of the water body and heap the seeds. Big seeds are collected in a harvest basket called 'Gaja' and cleaned by rinsing them in water. Small and light seeds were collected using fine



nets. White seeds of high quality with a sweet taste fetch premium prices in markets, whereas seeds that are slightly brown with salty flavor are considered to be of low quality. In a good season with optimum climatic requirements, farmers can harvest upto 2-3 tn/ha of water.

Processing

After harvesting, the workers stomp the seeds to remove the outer skin, clean the seeds, and spread them on a concrete floor for sun-drying(Khadatkar et al., 2020). After removing moisture and reducing the starch content in the seeds, seed roasting is performed to make them pop. They were cleaned again and sorted according to the size and color of the pops.

Nutritional im portance

The crunchy crispy fiber loaded makhana seeds (Figure 3.) have a low glycemic index, which is helpful for people with diabetes. Because it is low in calories, it can be consumed daily in different forms. It is rich in potassium, phosphorus, calcium, vitamin B1, carotene, Iodine and Iron. Today, people are obsessed with diet and weight loss, which makes the makhana a perfect choice for health-conscious consumers.

Challenges

1.Water lily flowers were the size of lotus in previous days but nowadays, due to excessive heat, the flowers are produced in relatively smaller sizes.
2.The plant usually contains a spiny thorn all over its surface and on its fruit (Figure 4 and 5). This makes harvesting cumbersome as workers are often pricked by barbs often (Ahmad, 2020).
3. If the ripened seeds remain in the water for a long time, they will not pop. Therefore, utmost care is provided to optimize the time to harvest.

Future perspectives

traditional cultivation methods, machines have been developed for cleaning and sorting seeds by the National Research Centre for Makhana. In 2002, it also released a high-yielding variety, 'Swarna vaidehi, 'which yielded 20 quintals/ha. The research center also successfully implemented the shallow water cultivation method in 1-2 feet to overcome the cultivation difficulties faced in the traditional deep-water cultivation of 6-7 feet. However, harvesting makhana is a difficult labor-intensive process that increases the cost of selling high as Rs.550-900/kg in India and upto 170 dollars abroad. The cost also represents the nutritional significance of the produce and growing demand among consumers. In the future, scientists can investigate the aspects of developing a makhana harvester that would reduce the tedious work involved in manual harvesting.

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AUGUST 2026
VOLUME 14 ISSUE 3

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