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

FARM INFORMATION BUREAU

KERALA KARSHAKAN

E-JOURNAL

THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

MARCH 2026
VOLUME 13 ISSUE 10

Farming Forward with Farm Women Power

INTERNATIONAL YEAR OF THE WOMAN FARMER 2026

INSIDE

KERALA KARSHAKAN
E-JOURNAL

FEBRUARY 2026 VOLUME 13 ISSUE 09

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THE FIRST ENGLISH FARM JOURNAL FROM THE HOUSE OF KERALA KARSHAKAN

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WOMEN FARMERS
Cultivating the Future

Agriculture often stands on the quiet strength of women. From seed selection and crop care to livestock management and household nutrition, women contribute significantly to sustaining rural livelihoods and food systems. Yet their role has long remained under-recognized, frequently viewed as supportive labour rather than professional farming. As we mark International Women's Day on March 8, it is important to acknowledge that women farmers are central to agricultural productivity, food security, and rural transformation. Evidence shows that closing gender gaps in agriculture can substantially improve farm productivity and reduce hunger.

The declaration of 2026 as the International Year of Women Farmers further strengthens global recognition of this reality. Across regions, women continue to demonstrate resilience and innovation despite challenges such as limited access to land, credit, and extension services. When women farmers receive equal opportunities, agricultural systems become more productive, sustainable, and inclusive.

This issue of Kerala Karshakan e-Journal presents a range of articles reflecting the evolving landscape of agriculture. Alongside discussions on women's role in farming, readers will find insights on innovative cultivation practices, traditional crop heritage, emerging functional foods, and advances in crop protection and postharvest management.

As agriculture adapts to changing environmental and economic conditions, knowledge sharing and inclusive innovation remain essential. This March issue celebrates the contribution of women farmers and highlights the collective efforts shaping a resilient and sustainable agricultural future.

Farming Forward
The Power of Women in Agriculture

ANJANA NAIR

Women have always remained an underrated element in general societal infrastructure. Despite being a central pillar of households, and having a profound influence in decision making in families, their role outside the household perimeter remains largely secondary. Agriculture has so far alluded only the status of 'helpers' to women workers in agriculture, and it is rare that they have been recognized as farmers at all. This disparity is conspicuous in their:

- Limited ownership of land and property
- Restricted access to institutional credit
- Lower participation in agricultural extension services
- Wage disparities in farm labour
- Exclusion from decision-making bodies

According to global policy discussions led by the Food and Agriculture Organization, closing the gender gap in agriculture could significantly increase farm productivity and reduce hunger. When women farmers receive

equal access to resources, yields improve, household nutrition rises, and rural poverty declines. Gender equality in agriculture is, therefore, not merely a social issue—it is an economic imperative, that needs urgent attention!

Can a role change in women bring about a change in productivity?

Yes. One of the most powerful examples of productivity improvement through women's participation comes from India's dairy sector, particularly under the cooperative model pioneered by Gujarat Cooperative Milk Marketing Federation. India's dairy transformation, especially during Operation Flood (1970–1996), focused not only on increasing milk production but also on organizing small farmers into cooperatives. Over time, women were actively encouraged to become members of village dairy societies instead of being represented only by male household heads.

When women were trained in scientific dairy practices it was observed that milk output per animal increased, mortality rates were reduced due to improved vaccination and care, quality control was stringently followed as women ensured better hygiene in milk handling, leading to higher quality milk and better prices and household incomes became more stable, leading to reinvestment in improved cattle breeds. Importantly, research supported by the Food and Agriculture Organization highlights that when women control income from agriculture, spending on nutrition, education, and farm inputs increases—creating a multiplier effect on productivity.

The system improved not just because more labour was added, but because women already performed most livestock-related tasks. Formal recognition as 'farmers' improved their motivation and accountability. Also, access to credit and veterinary services enhanced efficiency. So, productivity is not only about technology but, it is also about institutional inclusion. This case clearly proves that empowering women in agriculture is not just socially progressive — it is economically transformative.

Agricultural productivity gaps are often gender gaps in access—not gender gaps in capability

In rural Ethiopia, women historically worked extensively on farms but rarely held formal land rights or received agricultural training. Extension services typically targeted male household heads, even though women performed much of the farm labour.

The system improved not just because more labour was added, but because women already performed most livestock-related tasks. Formal recognition as 'farmers' improved their motivation and accountability.

Recognizing this gap, Ethiopia introduced:

- Joint land certification (listing both husband and wife on land titles)
- Women-focused agricultural extension programs
- Increased access to credit and cooperatives

When names of women were included on land certificates, they gained stronger decision-making power. They were more willing to invest in soil conservation and productivity-enhancing inputs. Household investment

in long-term improvements increased. Also when extension agents directly trained women, it was observed that adoption of improved seeds increased, fertilizer use became more efficient and crop management practices improved.

Research shows that productivity gaps between male- and female-managed plots were largely due to unequal access to inputs—not differences in ability. When access was equalized, yields on women-managed plots rose significantly. According to findings often referenced by the Food and Agriculture Organization, closing gender gaps in agriculture in Sub-Saharan Africa could increase total agricultural output by up to 2.5–4%, significantly reducing hunger.

When women farmers receive equal land rights, training, credit, and institutional recognition, entire agricultural systems become more productive and resilient.

Women and Sustainable Agriculture

Women are often custodians of traditional ecological knowledge. They preserve traditions, culture and ensure it is passed on to the next generation. When it comes to agriculture, their dominance in conserving indigenous seed varieties is evident. A 2023 study by Ramirez-Santos et al. shows that women globally—and particularly in mountain regions—are the primary conservers of agro-ecological knowledge.

Kamala Pujari born in a poor family in a tribal-dominated village in Koraput district, Odisha, received Padmashree in 2019 for her untiring efforts in preserving traditional paddy grains. Over the years, Kamala has successfully preserved hundreds of indigenous paddy seeds, and has also collected several endangered and rare types of seeds including paddy, turmeric, tili, black cumin, and

mahakanta.

Parappiamma, a tribal farmer from the Manithooki settlement in Vithura, Kerala, won the national 2020-21 Plant Genome Saviour Farmers Recognition award f or conserving the rare "Makkal Valarthi" (or "Koonthani") pineapple variety.

Practicing mixed cropping and organic farming, managing water and livestock resources and most importantly, preserving local biodiversity have been women farmers' prerogative since long. In the era of climate change, their knowledge becomes even more valuable. Women-led farming initiatives frequently emphasize sustainability, soil health, and community resilience. The International Year of Women reinforces the need to integrate women's voices in climate-resilient agricultural planning and agri-policy frameworks.

The United Nations has declared 2026 as the International Year of the Woman Farmer (IYWF 2026) to recognize the vital, yet often overlooked, role women play in global agrifood systems, food security, and rural economies. Led by the Food and Agriculture Organization (FAO), this initiative aims to drive policy action, close gender gaps in access to resources, and empower women in agriculture.

laborers to cooperative leaders and exporters. When women gained training in quality grading and export standard, access to international buyers improved price realization and received premium "women-grown coffee" branding, household incomes rose generously. Moreover, community-level investments in health and education increased and coffee productivity improved

agriculture today intersects with multiple global goals—food security, poverty reduction, climate action, and gender equality. The International Year of Women acts as a reminder that development must be inclusive. Policies must:

- Ensure joint land titles
- Promote women-centric credit schemes
- Strengthen self-help groups and cooperatives
- Provide gender-sensitive agricultural extension services
- Support childcare and social security for rural women

Such measures shift women from being unpaid labourers to recognized economic agents.

The International Year of Women is not simply a commemorative observance; it is a call to re-evaluate structures of inequality. In agriculture,

Kamala Pujari born in a poor family in a tribal-dominated village in Koraput district, Odisha, received Padmashree in 2019 for her untiring efforts in preserving traditional paddy grains.

Entrepreneurship and Agri-Value Chains

Agriculture today is recognized more as agribusiness and women has been found to be active participants in this new found business model. Dairy and poultry enterprises, Food processing units, Farmer Producer Organizations (FPOs) and Digital agri-marketing platforms are strongholds of women.

In Rwanda, women coffee producers moved from being farm

due to better processing techniques.

By promoting women's leadership in agri-value chains, economies can move from subsistence farming to value-added production. Skill development, digital literacy, and market linkage programs targeted at women can transform rural landscapes.

Policy Relevance in the Contemporary Context

The relevance of women in

where women form the invisible backbone of production and food security, recognition must translate into rights, resources, and representation. Empowering women farmers is not an act of charity—it is a strategic investment in sustainable development, resilient food systems, and inclusive economic growth.

When women thrive in agriculture, communities prosper, food systems stabilize, and nations progress. ■

Sky Farming

How a Kerala Woman Took on Wild Boars, Disease, and Won

DR. SMITHA K.P.[1], DR. APARNA G.S.[2] AND DR. MARY REGINA F.[3]

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As the world marks the International Year of the Woman Farmer (IYWF), Smt. Rathnam's journey highlights the vital role women play in global food security, nutrition, and agricultural sustainability. Women farmers are the backbone of smallholder agriculture, producing food, conserving biodiversity, preserving traditional knowledge, and nurturing resilient farming systems, despite facing challenges like limited access to land, credit, and technology. Rathnam's Sky Farming model embodies the essence of

> Agriculture is often seen as a peaceful way of life. However, for many small and marginal farmers, each day brings a fight against shrinking land, rising costs, wildlife attacks, and soil diseases.

IYWF: innovation arising from necessity, sustainability rooted in tradition, and leadership shaped by experience. By turning challenges into opportunities, she strengthens her own livelihood while also promoting healthier food systems, climate resilience, and community empowerment. Her story shows that empowering women farmers is essential for securing the future of agriculture and nutrition worldwide.

Agriculture is often seen as a peaceful way of life. However, for many small and marginal farmers, each day brings a fight against shrinking land, rising costs, wildlife attacks, and soil diseases. In a small corner of Mullassery Block in Thrissur district, one woman has transformed these challenges into a chance for innovation, creating a unique farming model she calls "Sky Farming."

From personal struggle to agricultural innovation

Smt. Rathnam's journey into innovation emerged from her struggles. As a cancer survivor and dedicated natural farmer, she lives in a rented house on very little land. While recovering at her brother's home, she saw wild boars repeatedly destroy crops, a familiar issue for many farmers in Kerala. Instead of giving up, Rathnam asked a simple question: How can a farmer grow food safely when land is small and animals are plentiful? She found that the answer lay not on the ground but above it.

What is Sky Farming?

Sky Farming is Rathnam's vertical farming system created for small landholdings and areas prone to wildlife attacks. Crops are grown in vertically arranged grow bags attached to sturdy pillars, keeping them well out of reach of wild boars and other animals. What makes this system truly special is its eco-friendly design. Unlike traditional plastic grow bags, Rathnam's bags are made from locally available coconut fronds, reinforced with non-woven fabric, and finished with a light cement wash for durability. Each grow bag lasts about five years, making this approach both economical and sustainable. Sky Farming addresses multiple issues faced by small farmers simultaneously:

- Maximum use of space: Traditional methods allow only 2–3 grow bags, while Rathnam's vertical setup can support up to 12 in the same area.

- Complete protection from wild animals: Since crops are elevated, wild boar damage is eliminated.
- Reduced soil-borne diseases: Growing crops above ground significantly decreases disease occurrences.
- Plastic-free farming: Coconut-frond grow bags provide a clean alternative to plastic, cutting down on soil and water pollution.

Composting the natural way

At the core of Rathnam's success is her commitment to natural farming. She makes her own nutrient-rich compost using materials like poultry manure, goat manure, coir pith, dried and green leaves, and cow urine. Her method uses a vertically placed perforated PVC pipe in the compost heap to ensure even aeration and to make applying cow urine easy. The compost is layered, mixed regularly, and within just 45 days, it becomes a nutrient-rich medium ideal for vegetables, tubers, and medicinal plants.

Diversity in crops

Key emphasis on cultivating a diverse variety of vegetables is the backbone of Smt. Ratnam's sustainability. By cultivating a variety of seasonal and perennial vegetables like leafy vegetables, gourds, bhindi, brinjal, chilli, and other nutritious vegetables, she is able to harvest them throughout the year. By diversifying, she is able to mitigate risks and increase her income and nutritional security. Rather than relying on a single crop, she has developed a sustainable production system that promotes crop rotation, mixed cropping, and staggered planting. Rathnam currently focuses on growing medicinal ash gourd, thereby providing rare and healthy seedlings to fellow farmers. She has also successfully added elephant foot yam to her Sky Farming system, a crop that is popular, especially those in smaller sizes. Through her efforts, she is not only cultivating crops but also:

- Reducing crop losses
- Supporting fellow farmers with quality planting material
- Promoting sustainable, low-cost alternatives
- Showing that innovation is possible even with limited resources

More than a method..., a movement

Sky Farming represents more than just a farming technique; it's a philosophy aligned with nature. Smt. Rathnam passionately promotes natural farming principles, avoiding chemicals and encouraging composting, crop rotation, and eco-friendly inputs among farmers in her community. She continues to refine her Sky Farming model, striving to make it more

cost-effective and accessible for small, urban, and marginal farmers.

A blueprint for resilient agriculture

From facing cancer to tackling wild boars, Smt. Rathnam's journey stands as a testament to resilience that transcends personal and professional boundaries. At a time when illness could have silenced her dreams, she chose instead to rebuild her life through farming. When wild boars destroyed her crops and soil-borne diseases threatened her livelihood, she did not retreat, she reimagined. Her pioneering Sky Farming model, built on raised platforms and innovative cultivation techniques, transformed vulnerability into strength. It is not merely a production system; it is a symbol of perseverance and courage.

Smt. Rathnam passionately promotes natural farming principles, avoiding chemicals and encouraging composting, crop rotation, and eco-friendly inputs among farmers in her community.

In the context of the International Year of the Woman Farmer (IYWF), her story acquires even greater significance. Smt. Rathnam embodies the spirit that IYWF seeks to celebrate: a woman who is not just a cultivator, but a problem-solver, entrepreneur, climate adapter, and community inspiration. Her Sky Farming model offers a replicable, eco-friendly solution for areas grappling with wildlife intrusion, shrinking landholdings, labour shortages, and soil degradation. By elevating cultivation above ground, she has demonstrated how small and marginal farmers, especially women managing homesteads, can produce safe, high-value vegetables with reduced risk. Such innovations align closely with global goals of climate resilience, sustainable intensification, and inclusive agricultural development that IYWF promotes.

More importantly, her journey challenges traditional narratives about women in agriculture. She is not merely "helping" on a farm, she is leading, innovating, and influencing. She represents thousands of women who convert adversity into opportunity and transform homesteads into hubs of food security. In an era when agriculture faces climate uncertainties, market volatility, wildlife conflicts, and resource constraints, her innovation reminds us of a powerful truth: "Sometimes, the best way forward is to rise above the problem."And in doing so, women farmers like Smt. Rathnam are not just cultivating crops, they are cultivating resilience, dignity, and hope for a more sustainable future.■

Kuttiattoor Mango

A GI-Tagged Legacy of Tradition and Taste

VARADA ARUN, MANJUSHAR.S., RAJI VASUDEVAN NAMBOODIRI

Imagine walking into a village in North Kerala where the landscape is painted with heavy-laden canopies every summer, and every courtyard tells a story of a golden fruit. While India celebrates it's globally famous GI-tagged legends—like the buttery Alphonso from Maharashtra, the honey-sweet Gir Kesar from Gujarat, or the fragrant Dusseheri from Uttar Pradesh—the people of Kannur have quietly nurtured their own masterpiece: the Kuttiattoor Mango. To a stranger, this might seem like just another fruit, but in the "Mango Village" of Kannur, these trees are inseparable parts of the cultural and homestead farming fabric, passed down through generations like a living heirloom.

The story of this mango begins nearly three centuries ago,when the seedlings travelled from Neeleshwaram royal family in Kasaragod to find a new home at Chaathoth Tharavadu in Kuttiattoor. There, the Nambiar family took these royal guests and planted them in their soil, preserving and nurturing the trees with devotion that they became an inseparable part of their family identity. The journey of how this celebrated variety acquired its local names is a fascinating story rooted in both royal legacy and village traditions.One popular legend tells of a local trader who carried a basket of these exceptional fruits to the Irikkur market. When struck by the fruit's unique beauty and taste, curious buyers asked for the name of the variety. The trader, not knowing a formal name, simply replied that the mangoes came from the "Nambiar household". From then, the name "Nambiar manga" was born and quickly spread across the region. Today, while the world knows it as Kuttiattoor mango, it still carries the echoes of its history in local names like Kannapuram manga, Kunjimangalam manga and Vadakkumbhagam manga. In 2021, it became the first mango from Kerala to receive Geographical Indication (GI) status. The GI recognition of Kuttiattoor mango was achieved through the coordinated efforts of Kerala Agricultural University, Department of Agriculture & Farmers' Welfare, Kuttiattoor Mango Producer Society and Kuttiattoor Grama Panchayat.

Kuttiattoor mango is cultivated across a wide area in Kannur district of North Kerala. It is grown in 19 Grama Panchayaths—namely Kuttiattoor, Kolachery, Mayyil, Koodali, Munderi,Malappattam, Kunjimangalam, Ayyankunnu, Payam, Aralam, Kannapuram, Keezhallur, Narath, Pappinisseri, Kalliasseri,Cherukunnu,Ezhome, Pattuvam, and Cheruthazham. Among these areas, cultivation is most extensive in Kuttiattoor Panchayath. Considerable area of cultivation is also seen in Mayyil, Koodali, Munderi, Kunjimangalam, Ayyankunnu, and Kannapuram Panchayaths, showing the wide acceptance and popularity of this mango among farmers in the district.

The story of this mango begins nearly three centuries ago,when the seedlings travelled from Neeleshwaram royal family in Kasaragod to find a new home at Chaathoth Tharavadu in Kuttiattoor.

What makes Kuttiattoor mango different?

The special quality of Kuttiattoor mango comes from the close link between the variety and the place where it is grown. The local soil and climate, together with the natural characteristics of the cultivar, give this mango its distinct identity and make it different from other mango varieties. Its fruits are a visual delight, boasting a vibrant orange-yellow hue on both skin and flesh, accompanied by rich taste and pleasing aroma. A special feature is that ripe fruits do not show black spots or patches on the skin. The skin is thin, but holds well to the flesh. The flesh is neither too soft nor too hard, with medium juiciness and only moderate fibre, making it easy and pleasant to eat. Traditionally, mangoes were ripened naturally by keeping them in cardboard boxes or gunny sacks along with Kanjiram (Strychnos nux-vomica) leaves, dried grass, or hay, reflecting how closely this mango is connected to the food habits and traditional practices of the region. Total soluble solids (TSS) is an important quality parameter in mango, as they indicate sweetness and overall fruit quality. In Kuttiattoor mango, the TSS is at a medium level, ranging from 12.62 to 15.40 °Brix. The fruit also has titrable acidity, ranging from 0.14 to 0.23 percent, which contributes to its pleasant taste. In addition, Kuttiattoor mango is relatively rich in vitamin C, providing good antioxidant properties. The fruit also remains as a versatile star in the local kitchen, where tender mangoes are used for traditional pickles and raw slices provide the distinctive flavour for heritage dishes such as fish curry. In earlier times, the young branches and tender leaves were traditionally used for brushing teeth, while the mashed mango seed served as an ingredient in preparing dishes like payasam and appam, highlighting the tree's multiple household uses. Traditional preparations such as maangakkachu and mangapperakku, once common in every household, further reflect the deep-rooted connection between the crop and local life.

The success of this golden fruit lies largely in its unique and well-adapted flowering and fruiting behaviour. Unlike many other mango varieties, these trees begin flowering as early as the second week of November and reach full bloom by late December. As a result, the fruits mature early and are ready for harvest between late March and mid-May. This early harvesting period allows farmers to complete the harvest before the onset of the south-west monsoon, thereby reducing the risk of crop damage due to heavy rains. Furthermore, this early maturity provides farmers with a valuable market advantage, enabling them to sell their mangoes ahead of other varieties and secure better returns. Another important biological advantage of this variety is its polyembryonic nature. The seeds are polyembryonic, and nearly 90 per cent of the seedlings develop true to the mother tree, naturally preserving the same quality, taste, and desirable characteristics of the parent. This ensures genetic uniformity and consistency in fruit traits across

generations. As a result, farming families can easily expand and maintain their orchards using seedlings, without relying on methods such as grafting, thereby making propagation simpler, reliable, and accessible.

Kuttiattoor Mango Producer Company

The Kuttiattoor Mango Producer Company, registered under the Companies Act 1956, is actively involved in harvesting, grading, marketing, and processing of mangoes, allowing member farmers to secure better prices by managing all operations directly. In addition to the domestic market, the company has expanded its reach to nearby districts such as Kasaragod, Kozhikode, and Wayanad. A mini processing plant operates at Kuttiattoor, creating value-added products that diversify mango's utility. Key products include mango squash, jam (from ripe and green mangoes), pickle, raw mango powder and sun-dried mango slices. Under this organised system, grades are fixed according to the size and beauty of fruits, with those exceeding 300 grams fetching a premium price. These high-quality mangoes are supplied to major markets across the region, including Farook, Vadakara, Manjeri, Perambra, Kanhangad, Thaliparambu, Thalassery, and Mattannur. Nearly 15 tonnes of mangoes were sold through the Kuttiattoor Mango Producer Company.

Kuttiattoor mango faces several production and marketing constraints, including the large size of the trees, which makes harvesting difficult and costly; changing climate conditions affecting yield and quality; lack of cold storage and post-harvest facilities; and limited consumer awareness of its Geographical Indication (GI) status. These factors currently restrict its wider commercialisation and market expansion. However, the prospects remain highly encouraging in view of the increasing demand for mangoes. According to the Food and Agriculture Organisation 2023, India is the world's leading producer and consumer of mangoes, contributing about 40–45 per cent of global production, and mangoes continue to be one of the most widely consumed fruits in the country. Furthermore, mango accounts for about 40 per cent of India's total fruit production, reflecting its strong domestic demand and economic importance. With improved awareness of its GI status, better infrastructure, and strengthened marketing support, the Kuttiattoor mango has strong potential to gain wider recognition and emerge as a valuable and economically important fruit in the future.

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The Power of Palm Pollen
Nature's Hidden Super food

Pollen capsules

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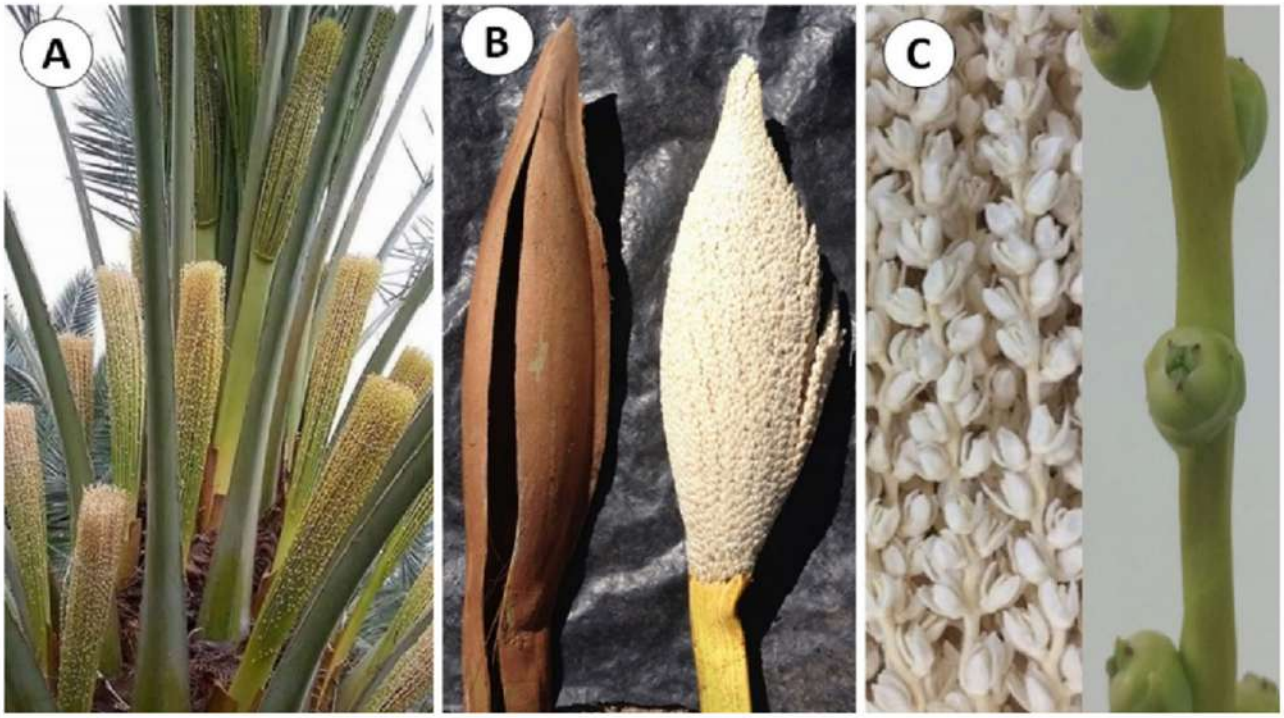
Although the term pollen was established in the 17th century from the Latin word which defines fine powder (flour), this plant material has been known as "food" for centuries. Pollen is recognized as an excellent dietary supplement for human nutrition, which is why it can be found in different forms on the market (granules, capsules, tablets, pellets, and powders). But, the digestibility of pollen's nutrients is strongly affected by the presence of a pollen shell, which can decrease the bioavailability of nutrients by 50% and more. Since consumers have become more aware of the benefits of a healthy diet and the necessity to improve pollen digestibility, different pollen-based functional food products have been developed and extensive studies were done to estimate the beneficial effects of pollen-based feed on animal growth, health, and rigor mortise stage.

Nowadays, pollen is often recognized as the "only perfectly complete food" and "the world's best food product". The dominant presence and high content of carbohydrates, proteins, and lipids highlights pollen as an ideal natural supplement that provides energy; it has good nutritional value, regulates certain biochemical functions, and strengthens the body's immune and physiological systems. Furthermore, pollen is a rich source of different important compounds vitamins (with the prevalence of group-B vitamins), carotenoids (such as lutein, β-cryptoxanthin, and β-caroten), minerals, and polyphenols, which makes it attractive for use in the diets of children and adults suffering from certain avitaminoses and loss of appetite.

Due to the diversity of active natural metabolites, especially vitamins, carotenoids, and polyphenols, pollen has a



Date palm pollen

significant biological activity, expressed as the antioxidant, antibacterial, and anti-carcinogenic activity and the hepatoprotective, and the cardioprotective effect. Furthermore, pollen is recognized as a good tool for the therapeutic treatment of several different non-allergic diseases. It was reported that the flower pollen extracts can be used as a complementary remedy for the treatment of the benign prostatic hyperplasia, chronic prostatitis, and vasomotor symptoms in women, but its clinical efficacy should be further tested. The most important pollen compounds which are believed to possess the most prominent pharmacological activity are essential fatty acids, phospholipids, phytosterols, flavonoids, and phenolic acids.

When we think of palm trees, the first images that come to mind are coconuts, dates, or towering silhouettes against blue skies. But beyond their fruits and oil, palms carry another treasure — pollen. Tiny, golden, and often overlooked, palm pollen is emerging as a powerful dietary supplement with impressive health benefits. Palm pollen is the fine powder released from the flowering structures of palm trees such as date palm, coconut palm, and oil palm. It contains the male reproductive cells of the plant and is traditionally collected during flowering season. Countries like Egypt, Saudi Arabia, India, and Southeast Asia have used palm pollen for centuries in traditional medicine — and now science is beginning to validate many of these ancient claims.

Powder form of date palm pollen

Palm pollen is biologically rich, containing essential amino acids, vitamins A, B-complex, C, and E minerals like selenium, magnesium, zinc, iron, antioxidants, and plant-based proteins. Thesenutrients make it beneficial across many health systems

Health Benefits

1. Boosts fertility in both men and women.
2. 2. Acts as a natural energy booster.
3. 3. Supports brain and nerve function. 4. Strengthens immunity and reduces oxidative stress.
4. Consumption Forms: Palm pollen can be consumed as powder, tablets, capsules, or mixed with honey or warm milk.

The Future of Palm Pollen

With increasing scientific and commercial interest, palm pollen is gaining value as a nutraceutical. Research is exploring its use in fertility support, functional foods, and anti-aging formulations. Palm trees have supported human life for thousands of years — and palm pollen may soon secure its place as a mainstream superfood.

Palm pollen is a fine yellow powder produced from the male flower clusters of palm species such as the date palm (Phoenix dactylifera), coconut palm (Cocos nucifera), arecanut palm (Areca catechu) and oil palm (Elaeis guineensis). For centuries, palm pollen has been traditionally consumed in regions across the Middle East, Asia, and parts of Africa for its nutritional and therapeutic properties. With increasing scientific interest, palm pollen has emerged as a promising natural dietary supplement because of its rich bioactive compounds, micronutrients, and potential health benefits.

Composition and Nutritional Value

Palm pollen is valued for its diverse biochemical profile. It contains approximately 22–30% protein, including essential amino acids such as lysine, valine, leucine, methionine, and phenylalanine. These amino acids support muscle development, metabolism, and cellular repair.

Coconut palm pollen powder

It is also a source of vitamins including vitamin A, B-complex (B1, B2, B6, and folic acid), vitamin C, and traces of vitamin D. The presence of minerals such as magnesium, calcium, iron, potassium, zinc, and selenium contributes to its potential role in supporting immunity, oxygen transport, and bone health.

Palm pollen contains phytosterols, flavonoids, carotenoids, and natural antioxidants, which help combat oxidative stress. Additionally, it has healthy fatty acids, natural enzymes, and polysaccharides that contribute to its biological and nutritional functions.

Traditional Uses and Health Benefits

Historically, palm pollen has been used in various cultures for:

- Enhancing general strength and vitality
- Supporting reproductive health
- Boosting energy and stamina
- Improving digestion
- Revitalizing the body after illness

In some regions, palm pollen is mixed with honey, milk, or herbal preparations to improve taste and enhance benefit synergy. Although research is still growing, several potential benefits have been associated with palm pollen. These include:

1. General Nutritional Support

   Due to its dense nutrient content, palm pollen may help support daily nutritional requirements. It supplies amino acids, minerals, vitamins, and natural enzymes essential for metabolic and physiological processes.

Flowers of date palm

2. Antioxidant and Cellular Protection

   Palm pollen contains natural antioxidants such as phenolics, flavonoids, and carotenoids. These compounds help neutralize free radicals and reduce oxidative stress, which is linked to aging and metabolic imbalances.

3. Digestive and Metabolic Support

   Traditional practices suggest palm pollen may support digestion and metabolism. Its fiber content and natural enzymes may help improve gut functioning and nutrient absorption.

4. Immune System Support

   The micronutrient composition, especially zinc, selenium, vitamin C, and flavonoids, contributes to immune defense. These nutrients are important for maintaining healthy immune cell activity and fighting infections.

5. Reproductive Wellness (Traditional Use)

   In traditional medicine, palm pollen is used to support reproductive wellness and physical vitality. While some initial scientific studies are ongoing, this benefit remains mainly traditional and should be interpreted cautiously.

Forms of Use

Palm pollen is available in different forms depending on consumer preference and processing technology:

- Raw Powder
- Capsules or Tablets
- Granules
- Honey-blended products
- Extracts for dietary supplement formulations

It can be taken alone or added to smoothies, warm milk, cereals, or functional food products.

Recommended Intake

There is no universal standard dosage. However, general use recommendations from nutraceutical formulations suggest:

1–5 grams per day depending on form and purpose

Children, pregnant individuals, or those with medical conditions should use palm pollen only under professional guidance.

Safety and Precautions

Although palm pollen is a natural product, some individuals may experience allergic responses, especially those with pollen sensitivities. Mild gastrointestinal discomfort may occur in new users. It is advisable to begin with a small dose to check tolerance. People undergoing hormone-related treatments or those with chronic health issues should consult a healthcare professional before long-term use.

Emerging Scientific Interest

Researchers are also exploring its potential roles in metabolic health, anti-inflammatory action, and micronutrient supplementation. However, more detailed clinical studies are needed to confirm therapeutic claims. With increasing global demand for natural and plant-based supplements, palm pollen is being studied for its potential roles in:

- Functional food development
- Natural antioxidant formulations
- Nutraceutical blends
- Energy and vitality supplements

Conclusion

Palm pollen is a nutrient-rich natural resource traditionally valued for nourishment, vitality, and wellness. Its wide range of vitamins, minerals, protein, antioxidants, and bioactive compounds make it a promising dietary supplement. While its traditional uses are well established, modern scientific research continues to explore its potential health advantages. When used responsibly and in appropriate quantity, palm pollen may serve as a supportive addition to a balanced diet and healthy lifestyle. ■

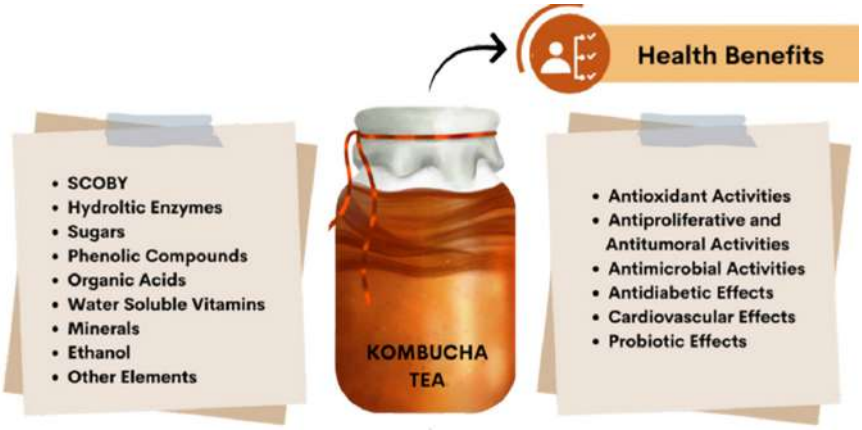
From Tea To Tang
Crafting Perfect Kombucha

JESIN, FATHIMA RASHA, SNEHA, ASWIN

Kombucha is a fermented tea made from sweetened black or green tea using a symbiotic culture of bacteria and yeasts (SCOBY), including species like Gluconobacter, Acetobacter, Lactobacillus, Zygosaccharomyces etc (Villarreal-Soto et al., 2018). It is traditionally brewed at home for 8–10 days. It produces acetic acid, a small amount of alcohol, CO_2, and has a slightly sweet, tangy, and fizzy taste (Filippis et al., 2018). It is believed to have originated in northeast China over 2000 years ago, with the consumption of kombucha first recorded in 220 BC in Manchuria. Kombucha contains a range of functional components, including vitamins, minerals, organic acid and phenolic component, and it also includes various other bioactives. The use of diverse fermentable ingredients suggests a need for further studies on its peptides, lipids, and other metabolites like acids, minerals, sugars, antioxidants, and other substances. It is particularly rich in bioactive compounds like polyphenols and glucuronic acid. Its potential health benefits are believed to result from the combined action of these compounds (Martínez Leal et al., 2018).

Fermentation

During preparation of Kombucha, the sweetened black or green tea is inoculated



General method of preparation

The flow chart containing the method of preparation is as follows,

with a portion of previously fermented kombucha (starter liquid) and a SCOBY (Symbiotic Culture of Bacteria and Yeast), which is a cellulose-based, jelly-like biofilm that forms on the surface of fermenting kombucha, a fermented tea beverage. The SCOBY acts as a living culture that ferments sweetened tea by converting sugars into organic acids, carbon dioxide, and a small amount of alcohol, giving kombucha its characteristic tangy and effervescent flavor. Over 7–14 days of fermentation, the yeast in the SCOBY converts sugars into ethanol, while bacteria oxidize ethanol into acetic and gluconic acids, forming a thick new SCOBY layer on the surface. These compounds are responsible for the characteristic sourness and preservative qualities of kombucha. As the process continues, the drink gradually shifts in flavor. Early on, it tastes sweeter due to the higher sugar content, but with longer fermentation, the sugar diminishes and acidity increases, creating a tart, vinegar-like profile. The relationship between yeast and bacteria is mutually beneficial: yeast generates the alcohol that bacteria require, while bacteria release acids that protect the brew from unwanted microbes. This coordinated microbial activity not only builds flavor and carbonation but also enriches the drink with probiotics, antioxidants, and other bioactive substances. In this way, the fermentation process turns simple sweet tea into a complex beverage with both distinctive taste and potential health benefits.

Microorganism involved

Kombucha strains were purchased from CPCRI and a typical ferment mainly consisted of five kinds of bacteria (Acetobacter xylinum, Acetobacter xylinoides, Acetobacter Ketogenus, Bacterium gluconicum,

Table 1: Major microorganisms of SCOBY	
Bacteria	Yeast
Acetobacter sp	Saccharomyces cerevisiae
Acetobacter aceti	Arxula adeninivorans
Acetobacter pasteurianus	Brettanomyces lambicus
Acetobacter nitrosofermentans	Brettanomyces claussenii
Acetobacter nitrogenifigens	Brettanomyces custersianus
Acetobacter xylinum	Brettanomyces bruxellensis
Acetobacter xylinoides	Candida kefyr
Acetobacter Ketogenus	Candida krusei
Acetobacter peroxydans	Hanseniaspora uvarum
Acetobacter intermedius,	Hanseniaspora meyeri
Allobaculum	Hanseniaspora valbyensis
Bacterium xylinum	Hanseniaspora vineae
Bifidobacterium	Herbaspirillum sp.
Bacterium gluconicum	Kazachstania telluris
Enterococcus	Kazachstania exigua
Gluconobacter oxydans	Kloeckera apiculata
Gluconacetobacter kombucha	Komagataella
Komagataea bacteriochaitica	Lachancea thermotolerans
Komagataeibacter xylinus (Gluconacetobacter xylinus or Acetobacter xylinum)	Lachancea fermentati
Lactobacillus fermentum	Lachancea kluyveri
Leuconostoc	Merimbla ingelheimense
Oenococcus oeni	Meyerozyma caribbica
Propionibacterium	Meyerozyma guilliermondii
Ruminococcaceae	Mycoderma sp
Thermus	Mycotorula sp.
	Saccharomyces ludwigii
	Schizosaccharomyces pombe
	Torulopsis sp.
	Torulaspora delbrueckii
(Sources: Yamada et al. (2012); Jayabalan et al. (2014), Jayabalan et al. (2014), Santos (2016))	

and Bacterium xylinum) and four kinds of yeasts (Saccharomycodes ludwigii, Schizosaccharomyces pombe, Saccharomyces cerevisiae, and Saccharomyces inconspicus). Major microorganisms of SCOBY are listed to Table1

End stage

Parameters to detect the end stage are; pH, Total soluble solids (TSS) and alcohol content.

Natural Defenses

Anti-oxidant activity

Kombucha is rich in antioxidants like polyphenols, catechins, and vitamin C, often exceeding levels in regular tea. These compounds reduce oxidative stress and may lower the risk of diseases like cancer, inflammation, and heart disease. Antioxidant levels vary with tea type, fermentation time, and added ingredients—green tea kombucha is typically highest. Fermentation enhances antioxidant activity, but excessive intake or certain combinations may have harmful pro- oxidant effects.

Anti-microbial activity

Kombucha shows strong antimicrobial effects against many Gram-positive and Gram-negative bacteria, yeasts, and molds. This activity is mainly due to organic acids (especially acetic acid) and phenolic compounds formed during fermentation. Black tea kombucha has potent antibacterial and antifungal effects, while green and oolong tea kombucha inhibit pathogens like E. coli, Shigella, Salmonella, and Vibrio. Its antibacterial components remain stable even at 100 °C for 20 min. Adding ingredients like lemon balm can further enhance its antimicrobial spectrum, possibly aided by antibiotic-like substances present in kombucha.

Kombucha also shows anti-inflammatory and anticancer potential due to compounds like glucuronic acid and fermentation metabolites. It can reduce inflammation, inhibit cancer cell growth, and limit their spread. Additions like lemon balm enhance its anticancer effects, and black tea kombucha has shown activity against several cancer types, suggesting possible therapeutic benefits.

Other benefits

Kombucha contains bioactive compounds and organic acids that contribute to multiple health benefits. Black tea kombucha shows strong cytotoxicity against various cancer cells, including colorectal, renal, osteosarcoma, and lung carcinoma, even after boiling. Organic acids, especially glucuronic acid, aid detoxification, hormonal balance, and antioxidant activity, while lactic acid supports circulation, prevents clots, and enhances antimicrobial effects. Animal studies report hepatoprotective properties, improved gut microbiota, and reduced non-alcoholic fatty liver disease. Probiotic microbes in SCOBY and microcellulose promote digestion, immunity, and intestinal health. Additional reported benefits include improved skin health, constipation relief, arthritis reduction, and weight loss.

Kombucha Moment in India

India's gut health market has doubled from ₹1,016 crore in 2021 to ₹2,070 crore in 2025, with kombucha holding a niche share of ₹70–80 crore. While the space is dominated by probiotic powders, yoghurts, and buttermilks, kombucha appeals mainly to affluent, Westernised youth seeking a premium, stylish alternative. Priced at around ₹100 for 200 ml, it's viewed as a craft, wine-like beverage rather than a mass-market option. Critics call it a passing fad, citing its high cost versus traditional options. However, brewers argue that its shelf stability, taste, and link to India's fermentation heritage give it staying power. Research on using the kombucha SCOBY to ferment traditional and lactose-free milk has produced drinks that meet FAO/WHO standards and contain beneficial microorganisms and organic acids (Kruk et al., 2021). These products show potential health benefits, though improvements in cost, sensory quality, and efficacy are needed.

Additionally, kombucha fermented with turmeric, Paeoniae alba, and black tea has demonstrated enhanced antibacterial and antioxidant properties, and significantly reduced inflammatory cytokine expression in LPS-stimulated cells—indicating its potential role in managing inflammation and sepsis (Su et al., 2023)002E■

Chaga
A superior medicinal mushroom with potential health benefits

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Inonotus obliquus, commonly known as chaga mushroom, a nutrient-dense fungus growing on birch trees in cold climates, valued for high antioxidant levels (melanin and polyphenols) and has potential immune-boosting properties. It is a type of parasitic fungus that primarily grows on birch trees as a blackened crusty mass on the trunk. They grow well in cold climatic conditions where the winter is a bit harsh, which include places like Northern Europe, Russia, Siberia, Canada, and Alaska, etc. Chaga mushrooms have been used for centuries in traditional medicine, to boost immunity and improve overall health. They are known to contain a high amount of antioxidants, which provide immense health benefits such as enhancing the body defence mechanism, reducing inflammation, and help in fighting cancer. Chaga is also known by other names, such as black mass, clinker polypore, birch canker polypore, cinder conk and the sterile conk trunk rot (of birch).

Chaga produces a woody like growth, or conk, which looks similar to a clump of burnt charcoal have roughly 10–15 inches in size. But they have a unique appearance like that of burnt charcoal on the outer side, and a soft, orange core towards

the inside. With an appearance similar to burnt charcoal, it has been harvested for centuries as a traditional medicine. Though it looks ugly, the chaga mushroom is gaining popularity in the other parts of the world because of its potential health benefits..

Health Benefits of Chaga Mushrooms

Chaga mushroom has the following potent health benefit

1. **Protects Against Liver Damage**

   Lab and animal studies suggest that chaga mushrooms may help prevent or reduce liver damage. One study found that chaga extract protected liver tissue from the harmful effects of tetra-butyl hydroperoxide, a chemical known to cause liver damage.. The antioxidants in chaga mushrooms may also reduce oxidative stress, which plays a role in chronic liver diseases like non-alcoholic fatty liver disease.

2. **Supports the Immune System**

   Chaga mushrooms contain beta-glucans, natural compounds that may enhance immune function. Early research in mice suggests that chaga extract may regulate cytokine production, which helps coordinate the immune system and strengthen the body's defence against infections, from minor colds to more serious illnesses.

3. **ReducesInflammation**

   Inflammation is a natural defense mechanism when the body fights illness. However, chronic inflammation can damage tissues and contribute to conditions like rheumatoid arthritis, heart disease, autoimmune disorders, and even depression. Studies on chaga mushrooms suggest that the extract can help reduce the production of harmful cytokines, potentially lowering inflammation and preventing the development of chronic inflammatory conditions.

4. **Lowers cholesterol levels**

   Studies revealed that it can reduce total cholesterol, LDL cholesterol and triglycerides and can increase HDL cholesterol

5. **Reduces heart diseases and rheumatoid arthritis**

6. **May Help Prevent Cancer**

   Researchers are investigating the potential of chaga mushrooms to prevent or slow the growth of cancer. Chaga mushrooms are rich in antioxidants, which protect cells from damage

caused by free radicals and oxidative stress—factors that contribute to cancer development. One study found that chaga extract could inhibit the growth of lung, breast, and cervical cancer cells in a petri dish and slow down the tumor growth in mice. Another study identified triterpenes in chaga mushrooms that can destroy tumor cells without harming healthy tissue. While these findings are promising, more extensive human research is needed to establish the anti-cancer benefits of chaga

7. Blood Sugar Regulation: Chaga mushrooms may help lower blood sugar levels, making them beneficial for people with diabetes.
8. Promotes Gut Health: The fibre content in chaga mushrooms can support digestive health and promote a healthy gut microbiome
9. High in Antioxidants: Chaga mushrooms are rich in antioxidants, including polysaccharides, triterpenoids, and melanin, which help combat oxidative stress and protect cells from damage.

Cultivation of Chaga Mushroom

Chaga mushrooms are cultivated on living birches. For this, chaga mycelia are cultured in a laboratory, then small holes are drilled in the tree and are inoculated with 3-4 dowels (a wooden plug) containing the mushroom mycelia by inserting these into the holes which are drilled in the tree. Chaga cultivation doesn't need much management apart from inoculation and harvesting. Due to its rather slow growth, chaga cultivation fits best in low-yielding birch forests outside commercial forest management, it is also suitable for forest owners who live far away from their forest or for people without much time. After inoculation, the first chaga mushrooms are harvested after 5-9 years. For each birch tree it is possible to get about 2-4 harvests. The tree usually dies after 15 years, after having 2-4 harvests. However, the tree can still be harvested and sold as fire or fibre wood or used as mulch for compost or soil improvement.

Harvesting Chaga Mushrooms

Harvesting chaga mushrooms requires careful and sustainable practices to ensure the health of the host tree and the continued growth of chaga in the environment. For better yield, follow the key points below.

1. **Identification:** Look for mature birch trees with chaga growing on their trunks. Chaga appears as a blackened, crusty mass, often resembling burnt charcoal.
2. **Season:** The best time to harvest chaga is during the colder months when the tree's sap is not flowing, usually from late fall to early spring.
3. **Tools:** Use a sharp knife or chisel to carefully cut the chaga away from the tree. Avoid damaging the tree itself.
4. **Sustainability:** Only harvest a portion of the chaga to allow for regrowth. Overharvesting can harm the tree and reduce future chaga availability.

Chaga receipes for a healthy diet

Chaga Tea

Ingredients

- 1-2 teaspoons of chaga powder or a few chaga chunks
- 4 cups of water
- Honey or lemon (optional)

Bring the water to a boil in a pot. Add the chaga powder or chunks to the boiling water. Reduce the heat and let it simmer for 1-2 hours. The longer it simmers, the stronger the tea. Strain the liquid into a cup and add honey or lemon for flavor if desired.

Chaga Smoothie

Ingredients

- 1 teaspoon of chaga powder
- 1 banana
- 1 cup of almond milk (or any preferred milk)
- 1 cup of spinach
- 1 tablespoon of almond butter
- 1 tablespoon of honey (optional)

Add all the ingredients to a blender.Blend until smooth. Pour into a glass and enjoy nutrient-packed chaga smoothie.

Chaga Mushroom Soup

Ingredients:

- 1 teaspoon of chaga powder
- 1 onion, chopped
- 2 cloves garlic, minced
- 2 carrots, diced
- 2 celery stalks, diced
- 4 cups of vegetable broth
- 1 cup of mushrooms, sliced
- Salt and pepper to taste
- Olive oil

In a large pot, heat olive oil over medium heat. Add the onions and garlic, and sauté until fragrant. Add the carrots and celery, and cook until tender.Stir in the mushrooms and cook for a few more minutes.Add the vegetable broth and bring to a boil.Reduce the heat and let it simmer for 20 minutes.Stir in the chaga powder and season with salt and pepper. Serve hot and enjoy chaga mushroom soup

Chaga Energy Balls

Ingredients:

- 1 teaspoon of chaga powder
- 1 cup of oats
- 1/2 cup of almond butter
- 1/4 cup of honey
- 1/4 cup of chia seeds
- 1/4 cup of dark chocolate chips

In a large bowl, mix all the ingredients until well combined. Roll the mixture into small balls. Place the energy balls on a baking sheet and refrigerate for at least 1 hour and enjoy chaga energy balls as a healthy snack.

Other uses of Chaga Mushrooms

1. **Supplements:** Chaga extract is available in capsule or powder form, making it easy to incorporate into your daily routine.
   - **Capsules:** Contain powdered chaga extract and can be taken with water.
   - **Tinctures:** Alcohol-based extracts that can be added to water or taken directly.
   - **Powder:** Can be mixed into smoothies, coffee, or other beverages.
2. **Skincare:** Chaga is used in some skincare products for its antioxidant properties, which may help protect the skin from damage.
   - **Antioxidant Properties:** Chaga is rich in antioxidants, which help to protect the skin from damage caused by free radicals.
   - **Anti-Inflammatory:** Chaga's anti-inflammatory properties can help to soothe irritated skin and reduce redness.

Products

- **Creams and Serums:** Look for skincare products that list chaga extract as an ingredient.
- **DIY Masks:** You can mix chaga powder with other

natural ingredients like honey or yogurt to create a face mask.

3. **Tinctures:** Chaga can be made into alcohol-based tinctures, which are concentrated liquid extracts used for their health benefits

Ingredients

- Chaga chunks or powder
- High-proof alcohol (e.g., vodka)

Fill a jar halfway with chaga chunks or powder.Pour alcohol into the jar, covering the chaga completely.Seal the jar and store it in a cool, dark place for at least 4-6 weeks, shaking it occasionally. Strain the liquid into a dropper bottle. The tincture can be used by adding a few drops to water or directly under the tongue

Smt. Rathnam passionately promotes natural farming principles, avoiding chemicals and encouraging composting, crop rotation, and eco-friendly inputs among farmers in her community.

Disadvantages of using Chaga Mushroom

Eventhough, chaga mushrooms offer numerous health benefits, there are some potential side effects. The possible side effects are listed below.

1. Allergic Reactions: Some people may experience allergic reactions, such as itching, rash, or swelling, when consuming chaga.
2. Lowering Blood Sugar Levels: Chaga may lower blood sugar levels, which could be problematic for individuals with diabetes or those on blood sugar-lowering medications.
3. Interactions with Medications: Chaga can interact with certain medications, including blood thinners and immune-suppressing drugs. Hence, it's important to consult a healthcare provider if you take any medications.
4. Kidney Strain: Excessive consumption of chaga may strain the kidneys, especially in individuals with pre-existing kidney conditions. Chaga mushrooms are high in oxalates, which can increase the risk of kidney stones.
5. Digestive Issues: Some people may experience digestive discomfort, such as nausea or diarrhoea, when consuming chaga.

Tips to be followed for including chaga in your diet

- Consult a doctor or Healthcare Provider: Before adding chaga to your routine, especially if you have pre-existing health conditions or are taking medications, consult with a doctor. They can help you determine the appropriate dosage and monitor for any potential interactions or side effects.
- Start with Small Doses: Begin with a lower dose of chaga to see how your body reacts. Gradually increase the dosage as needed, but always stay within recommended limits.
- Monitor Blood Sugar Levels: If you have diabetes or are on blood sugar-lowering medications, regularly monitor your blood sugar levels to ensure they remain stable.
- Stay Hydrated: Drink plenty of water to help your kidneys process the compounds in chaga and reduce the risk of kidney strain.
- Avoid Combining with Other Supplements: Be cautious about taking chaga with other herbal supplements unless advised by a doctor or health care provider as interactions can occur.
- Document Any Side Effects: Keep track of any side effects you experience and report them to your healthcare provider. This can help them adjust your dosage or recommend alternative treatments if necessary.

Conclusion

Due to immense medicinal properties, it has high market demand, sustainability, long-term yield, value addition opportunities, eco-friendly, low maintenance as well as greater export potential. Even though this mushroom has excellent medicinal properties, more studies are needed to establish the relationship between chaga mushrooms and its properties on reduction of various disease is yet to be confirmed in humans through various studies.■

The Battle Against Taro Leaf Blight

Modern Approaches to an Age-Old Problem

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Taro (Colocasia esculenta) is a vital tuber crop with a rich history, believed to have originated in South East or South-Central Asia. Though one of the world's oldest crops, it remains a cornerstone of food security, particularly in developing nations. It holds the 9th position among global food crops, with a total production of 14.3 million tonnes across 49 countries. While Africa leads in production volume, Asia boasts the highest productivity, highlighting the crop's significant regional importance. In India, taro is a major crop cultivated across 40,000 hectares, providing a crucial source of nutrition for people of all backgrounds. Taro belongs to the Araceae family, a diverse group of plants including well-known species like elephant foot yam (Fig 1). The two main types, 'dasheen' and 'eddoe,' are cultivated for their unique corms and cormels. Taro's adaptability to a wide range of soil and climatic conditions from waterlogged swamps to dry, high-rainfall areas make it a resilient crop ideal for ensuring food security in a changing climate. Beyond its role as a staple carbohydrate, taro is a nutritional powerhouse. Its leaves, petioles, and corms are rich in dietary energy, starch, fiber, protein, and essential micronutrients like potassium and vitamin C. This nutrient density, coupled with the fact that all parts of the plant can be utilized, makes taro a zero-waste crop with immense potential to combat malnutrition and "hidden hunger." Despite its global significance and nutritional value, taro is often categorized as a "neglected and underutilized" or "orphan" crop. This has led to a lack of systematic research and genetic improvement, limiting

Fig 1 TARO

FIG 2 Taro field

its full potential. However, with its climate resilience, nutrient-rich profile, and adaptability, taro is being re-recognized as a "future smart food." This article explores the promise of this remarkable crop and the global efforts needed to elevate it from a neglected species to a major player in ensuring global food and nutritional security (Fig 2).

Taro Leaf blight

The taro crop, a vital staple for millions, is severely affected by taro leaf blight (TLB), a devastating disease caused by the fungus like water loving mold, Phytophthora colocasiae. While taro has nourished communities for centuries, this pathogen poses a significant and escalating threat, causing massive losses for farmers and jeopardizing global food security. TLB's impact is both swift and severe. It can destroy a taro crop in a matter of days, and its effects are felt in every part of the plant. The disease primarily attacks the leaves, which are the plant's "factories" for producing the energy needed to grow its corm. When left unchecked, TLB can wipe out up to 95% of a plant's leaf area, a loss so extensive that the plant simply cannot survive (Fig 3). The destruction of the leaves directly translates to a massive reduction in the corm's yield. Research in India, for example, has shown yield losses ranging from nearly 29% to over 55% in susceptible varieties. This not only diminishes the quantity of the harvest but can also lead to a post-harvest corm rot, causing heavy losses during storage .

Fig 3 Taro field with TLB infection

Symptoms of Taro leaf blight disease

Early detection before symptom development is critical. The disease is highly recognizable by its distinct symptoms and rapid progression. The first symptoms appear as small, dark, or light brown spots on the leaf surface, often at the tips and margins where water accumulates. These spots quickly enlarge into circular, brown lesions (Fig 4). Under humid conditions, a characteristic whitish ring of sporangia, the pathogen's reproductive structures become visible around the edge of the lesions. Under ideal conditions (cloudy, rainy weather with temperatures around 28°C), the disease spreads with alarming speed, destroying entire leaves within 3 to5 days. The infected leaves then hang from their long petioles, a tell-tale sign of the disease's advanced stage, giving the entire field a blighted appearance. Taro leaf blight (TLB) is a major threat to taro cultivation, and it is a problem that is highly influenced by the weather. Understanding how factors like temperature and humidity contribute to this disease is crucial for managing it effectively.

The TLB's favourable conditions: hot and humid weather

Taro leaf blight thrives in conditions that are warm and wet. When the air is humid and it is raining frequently, the blight can spread rapidly. This is why it's a big issue in tropical and subtropical regions. The most severe outbreaks happen when temperatures are just right around 20-22 °C

during the day and 25-28 °C at night. A humid atmosphere with 65% relative humidity during the day and 100% at night, along with overcast, rainy weather ris the perfect condition for the disease epidemic . Under these ideal conditions, taro leaves can be completely taken over by the disease in as little as 5–7 days. On the other hand, if temperatures are too cool or too hot, the disease's ability to spread is significantly reduced, even with high humidity and rain. The best conditions for an outbreak are when these perfect temperature and humidity levels last for 6–8 hours on three consecutive days, especially with light rain or morning dew.

The role of water and the disease cycle

Water is the primary way the TLB pathogen, Phytophthora colocasiae, gets around. It uses tiny, mobile spores called zoospores that are released when it is wet (Fig 5 & Fig 6). These spores are like little swimmers, moving through water on the lower leaves. When a zoospore lands on a taro leaf, it attaches itself, germinates, and penetrates the leaf, causing a new infection. Rainfall and irrigation help these spores move from plant to plant and even field to field. This is why proper drainage is so important. The disease can also survive in the soil or in infected corms (the underground stems of the taro plant). If a field has a history of blight, the pathogen can lie in wait, ready to strike again. This is particularly problematic in wetland taro cultivation, where water can easily carry the pathogen from one plant to another.

Why some plants get affected and others don't

Sometimes in a blighted field, some plants are severely infected while their immediate neighbours

FIG 4 Taro leaf infected with P.colocasiae

seem perfectly healthy. This is not just random; it is due to a combination of factors.

1. Host susceptibility: Not all taro plants are created equal. Some varieties, or cultivars, have a natural resistance to the disease. These are the plants that breeders look for when developing new, resilient varieties.

2. Microclimate: The environment around a specific plant, or its "microclimate," can also play a huge role. For example, older leaves lower in the plant canopy are more likely to get sick. Why? They are constantly being hit with a supply of spores from water runoff and dew, and they have a less waxy cuticle, which makes it easier for the spores to stick.

3. Planting Material: One of the most common ways the disease spreads over long distances is through infected planting material. Growers might unknowingly use infected corms, which introduces the pathogen to a new, healthy field.

Management of TLB

Ensuring the long-term viability of taro production necessitates a multifaceted Integrated Pest

Management (IPM) framework. To effectively combat the complexities of taro leaf blight a synergistic approach is required that synchronizes advanced cultural practices, judicious chemical application, and biological interventions with the deployment of resistant genotypes.

1. Cultural practices: The Foundation of good health

The first line of defense is simply good hygiene and smart farming. These cultural practices can make the environment less welcoming for the pathogen. For example, by planting taro with proper spacing , farmers can increase airflow. This helps leaves dry faster after a rain, robbing the pathogen of the wet conditions it needs to spread. A perfect example of this is to to use raised beds in taro fields. This simple change allows excess water to drain away, preventing the waterlogged conditions where the blight thrives. Similarly, removing and destroying infected leaves and plants from a field a practice known as sanitation is like cleaning up a battlefield after a skirmish. It removes the source of the pathogen, preventing it from spreading to healthy plants.

2. Chemical control: The emergency response

While cultural and biological strategies form the foundation of sustainable agriculture, chemical control remains a vital component of Integrated Disease Management (IDM) for providing immediate relief during high disease pressure. Systemic fungicides, particularly those containing metalaxyl and phosphonates, are highly effective against Phytophthora colocasiae due to their ability to circulate through the plant's vascular system and inhibit pathogen growth. However, to prevent environmental degradation and the emergence of fungicide-resistant strains, chemical application must be judicious and strategically timed. Research emphasizes that fungicides are most effective when applied preventively, ensuring thorough coverage of leaf surfaces especially the undersides where sporangia thrive. By integrating these targeted chemical interventions with other management practices, farmers can effectively halt disease outbreaks while minimizing the ecological footprint of their farming operations.

Current chemical recommendations

To manage TLB effectively, the following application schedule and dosages are recommended by technical guidelines:

- Prophylactic Spray: A protective spray should be administered 45 days after planting, even if symptoms are not yet visible
- Follow-up Treatments: Once symptoms appear, apply three additional sprays at 15-day intervals

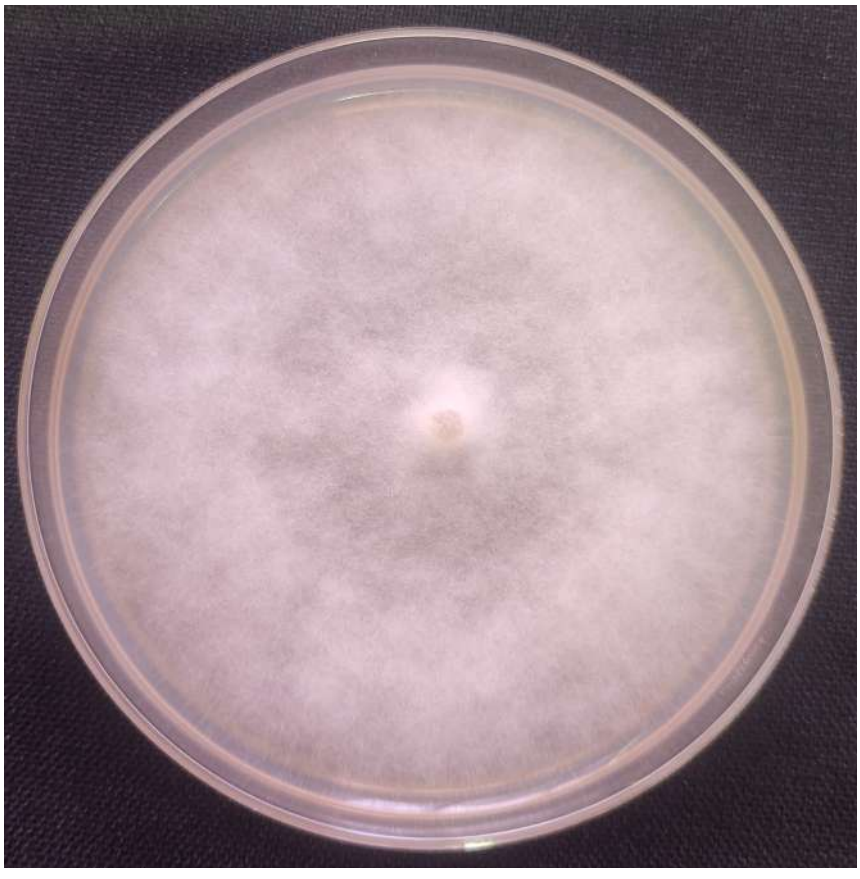
Recommended Fungicides: Use any one of the following treatments per liter of water:

- Metalaxyl 4% + Mancozeb 64% (68% WP): 1 g/l
- Mancozeb 75% WP: 2 g/l
- Potassium Phosphonate: 3 ml/l

Biological Control: Nature's own army

In recent years, biological control has emerged as a cornerstone of sustainable management for Taro Leaf Blight (TLB), offering an ecologically balanced alternative to chemical fungicides. This

Fig 5 P.colocasiae grown in carrot agar medium



strategy leverages the natural antagonisticinteractionsbetween beneficial microorganisms and the pathogen Phytophthora colocasiae. Key biological control agents, including Trichoderma, Bacillus, and Pseudomonas species, suppress the disease through diverse mechanisms: they outcompete the pathogen for resources, produce toxic antimicrobial compounds, and directly parasitize fungal mycelium. Beyond direct attack, these microbes also activate the plant's own immune system, a process known as induced systemic resistance, which primes the taro plant to defend against future infections. Furthermore, biopesticides derived from natural compounds like chitosan and various plant extracts have shown significant potential in inhibiting pathogen growth and enhancing plant resilience. Biological agents can be applied as soil amendments or foliar sprays. Foliar applications are particularly effective for colonizing leaf surfaces and preventing the airborne invasion of P. colocasiae spores.

Current recommendations for field application

For effective biological management, current protocols emphasize integrating these agents into the planting and maintenance phases:

- Seed Treatment (Cormels): For organic and sustainable cultivation, dip cormels in a Trichoderma enriched cow dung slurry (5 g of Trichoderma per 1 kg of cormels) for 10-15 minutes before planting
- Soil Enrichment: Apply Trichoderma-enriched vermicompost at a rate of 100 g per plant during the initial planting
- Maintenance: Re-apply the enriched vermicompost during intercultural operations (such as weeding and earthing up) to maintain a protective microbial presence in the rhizosphere

Resistant cultivars: Breeding the next generation

The most effective long-term solution for managing TLB is the development of resistant varieties, a strategy that moves away from chemical dependency toward genetic resilience. Research has shown that taro cultivars vary significantly in their susceptibility to the pathogen Phytophthora colocasiae. While many modern varieties are vulnerable, traditional landraces often possess natural defense mechanisms. In India, landmark studies identified varieties such as 'Ahina' and 'Poonam Pat' as early sources of resistance. ICAR-Central Tuber Crops Research Institute (CTCRI) identified 'Muktakeshi' and 'Jankhri' as highly tolerant varieties. These plants utilize a "hypersensitive response," where the plant cells at the infection site die off rapidly to starve the fungus and prevent it from spreading. By crossing these hardy traditional lines with high-yielding ones, breeders have produced superior hybrids like 'Sree Kiran, 'Bhu Sree, and 'Bhu Kripa'. These varieties are transformative for farmers, offering the dual benefit of high food production and natural immunity. Beyond the field, scientists are also focused on "gene banking"- collecting and storing diverse taro DNA from around the world. This international library of genes ensures that even if the blight fungus evolves, researchers have the genetic tools necessary to breed the next generation of resistant crops. For sustainable taro cultivation, the adoption of these resistant cultivars is the most reliable defense against crop failure.

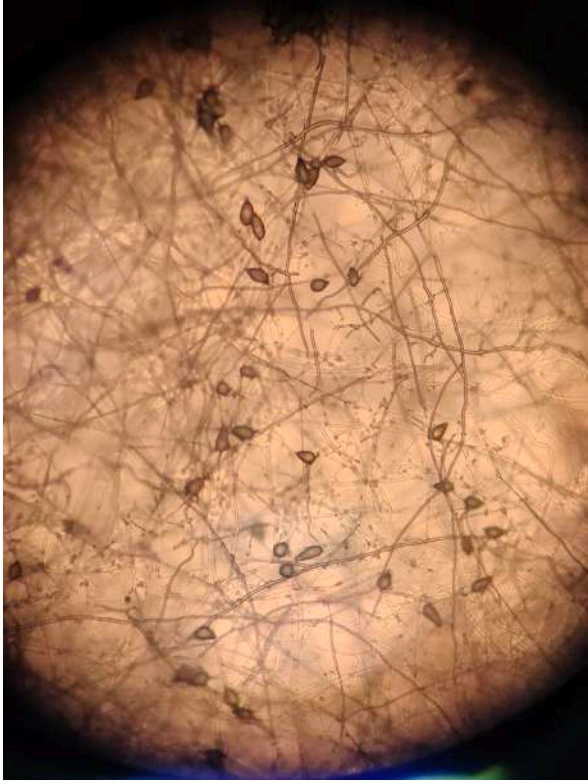


Fig 6 Microscopic view of sporangia of P.colocasiae

Conclusion

Effectively managing taro leaf blight (TLB) requires a holistic, integrated approach to combat its serious, multifaceted threat to global food security. Given the complex interplay between the pathogen's diversity, environmental conditions, and the taro plant's vulnerability, no single solution is sufficient. Instead, a unified defense is essential, combining diverse strategies into a layered approach. By understanding the disease's dynamics how it spreads in different climates and affects various taro varieties we can build a resilient system that leverages cultural practices, genetic resistance, and targeted treatments. This comprehensive effort is a shared global responsibility, demanding that we move beyond simple fixes to mitigate the blight's devastating impact and ensure taro, a cornerstone of nutrition for millions, remains a reliable food source for generations to come. ■

Wood apple

The tough crop for easy farming

DEVANANDHA A. S., ANUPAMA. S, SANGEETHA K.G

Despite being native to India, many traditional fruits are labelled 'exotic' in modern food culture. The perception arises mainly from their declining presence, limited utilisation, and reduced familiarity among customers. As a result, such fruits are viewed as rare or unusual rather than part of an everyday diet. Wood Apple, known as 'Vilamkay', is such an example of a native exotic fruit.

Wood Apple (Aegle marmelos (L.) Corea) is a hard-shelled, woody and rough fruit resembling a large ball of dried clay. Its colour ranges from dull greyish-white to a pale brown. Upon cracking the shell, the interior reveals a soft, mealy pulp. When unripe, it is white and astringent; when mature, it turns to a deep chocolate brown or dark maroon. The small crunchy seeds of wood apple are numerous, embedded in the dark pulp. Wood apple possesses a pungent, fermented aroma. Its flavour profile is a sophisticated balance of sharp acidity and deep raisin-like sweetness. The physical 'thud' vs 'bounce' is the most reliable physical test for maturity testing in wood apple: if the fruit is dropped from a height and it falls and bounces like a ball, it is unripe; if it falls with a thud, it is ripe.

Wood apple is a slow-growing tree that thrives in tropical to subtropical climatic conditions. It requires a significant amount of heat to ripen its fruit and develop its signature aromatic pulp. It flourishes in regions where temperatures range from 20°C to 35°C. Wood apple is exceptionally tolerant of high temperatures, often surviving in semi-arid zones where summer temperatures peak above 40°C. The tree is highly sensitive to cold. Wood apple prefers a dry, low-humidity climate. It grows best in areas with an annual rainfall of 500 mm to 1500 mm. The wood apple tree grows in sandy, loamy or even slightly saline soil. Wood apple is a sun-loving plant that requires at least 6-8 hours of sunlight a day. It is most often found in dry plains and forest regions.

The tree typically grows to a moderate height of 30 to 50 feet, with sharp, woody spines. The flowers of the wood apple are relatively tiny but numerous, usually measuring about 1 cm in diameter. The flowers are bisexual, growing as loose, branched clusters that emerge from the leaf axils or on the tips of young branches. The flower consists of five petals and five sepals, in which the petals of the flowers are typically a dull red, greenish-maroon, or pale yellow with reddish tinges that have a slightly leathery or waxy texture.

The tree typically begins to bloom between February and May, coinciding with the onset of the warm, dry spring. This ensures the fruits have the long, hot summer months to mature. Unlike the sweet, heady scent of citrus flowers, wood apple blossoms have a very faint, slightly pungent aroma that attracts specific local pollinators. In orchard farming, these trees must be widely spaced at planting (usually 8 to 10 meters apart) to prevent one tree's canopy

from shading another, as shade significantly reduces fruit yield and sweetness. The propagation of the wood apple can be sexual (seeds) or asexual (vegetative). Seed propagation is the most common method for the wood apple, particularly in wild or large forestry.

Wood apple seeds have a relatively short shelf life. So for the best germination rates, they should be sown within 2 to 3 weeks of extraction. Seeds are typically sown in nursery beds on polybags filled with a mixture of soil, sand and organic manure. Once the seedlings reach a height of about 20-30 cm (usually after 6-12 months), they are ready to be transplanted into the main field during the monsoon season. Vegetative propagation of wood apple is through budding and grafting, in which methods like patch budding and softwood grafting are preferred for producing true-to-type, high-yielding trees. Softwood grafting onto one-year-old rootstock in February provides the highest success rate (up to 96%), while in-situ grafting ensures more vigorous growth.

Wood apple has been used for culinary purposes, medicinal and therapeutic purposes, and as a value-added product. The primary use of wood apple is culinary, where its high acidity is leveraged to create a unique flavour profile. It is used as a refreshing beverage in the form of wood apple sherbet. The pulp is diluted with water, then blended with jaggery and black salt to create a cooling drink that serves as a natural antidote to sunstroke. In Indian households, the fruit is used for making chutneys and pickles. Its natural tartness mimics tamarind, making it a perfect base for spicy-sweet spreads that pair well with snacks. Wood apple is also a popular street snack. Vendors crack the shell, mix the pulp with salt, sugar and chilli powder and serve it back in its own 'natural bowl'. The astringent property of this fruit is effective as a remedy for diarrhoea and dysentery. Conversely, the fibre in the ripe fruit helps relieve constipation. The fruit is believed to help stimulate the liver and kidneys, aiding in the detoxification of blood.

The leaves and bark of the tree are sometimes used in decoctions to treat chronic cough and sore throat. This fruit is an excellent source of vitamin C, calcium, phosphorus and iron. Every part of the wood apple tree, from the shell to the gum, has a practical application beyond the kitchen. The shell of the wood apple is often used to craft

small containers, snuff boxes or decorative ornaments. The gum produced by the trunk of the tree is used in ink, dyes and varnishes. The wood is heavy and durable and is frequently used to make agricultural implements, tool handles, or construction posts. The leaves of the wood apple tree contain essential oils used in some traditional perfumes and cosmetics. The wood apple holds a sacred place in several cultures. In India, it is frequently offered to lord Shiva and lord Ganesha during festivals like Ganesh Chaturthi. The tree itself is often planted near temples as its presence is thought to bring cooling energy and spiritual grounding to the environment.

Wood apple represents a resilient economic lifeline for farmers in arid and semi-arid regions. For a farmer, one of the most significant attributes of the wood apple is its ability to turn marginal land into productive land. Unlike high-maintenance cash crops, the wood apple requires minimal irrigation and almost no chemical fertilisers. In an era of unpredictable monsoons, the wood apple's extreme drought tolerance ensures that a farmer's investment is protected even during years of low rainfall. Because the fruit has a long shelf life due to its hard, protective shell, farmers can store and transport it over long distances without the need for expensive cold storage infrastructure. There is a growing market for processed wood apple products. By converting raw fruits into pulp, jams or dried powders, farmers can move up the value chain, significantly increasing their profit margins compared to selling raw fruits at local markets. For the modern farmer, the wood apple offers a low-risk, high-reward opportunity. It is a tree that asks for very little - thriving on the sun and neglected soil - yet gives back in the form of nutritious food, medicinal remedies and a steady source of income.

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Chitosan
A Biopolymer for Postharvest Disease Management and Quality Preservation in Fruits and Vegetables

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Postharvest Losses: A Major Concern

Postharvest losses of fruits and vegetables pose a serious challenge to agricultural sustainability and farmers' income, particularly in tropical regions like Kerala. Even after harvest, produce remains biologically active and highly vulnerable to fungal infections, rapid ripening, moisture loss and quality deterioration. A significant proportion of fruits and vegetables is lost during postharvest handling due to diseases, mechanical injuries and improper storage practices. Reducing these losses is essential not only for improving farm income but also for ensuring food security and minimizing wastage.

Need for Eco-friendly Postharvest Solutions

The increasing concern over pesticide residues, environmental pollution and consumer health has shifted attention towards safer alternatives to chemical fungicides. Eco-friendly postharvest treatments that are effective, economical and safe for consumers are now gaining importance. In this context, chitosan, a natural biopolymer, has emerged as a promising material for managing postharvest diseases while maintaining quality.

Source and Nature of Chitosan

Chitosan is derived from chitin, a naturally occurring polysaccharide present in the shells of crustaceans such as shrimp and crabs. Through partial deacetylation of chitin, chitosan is produced as a biodegradable, non-toxic and biocompatible compound. Owing to its unique physicochemical properties, chitosan is widely explored for agricultural use, particularly as an edible coating and disease-suppressing agent in postharvest systems.

Antifungal Activity of Chitosan

One of the major advantages of chitosan is its broad-spectrum antifungal activity. Chitosan interferes with the normal functioning of fungal cells by disrupting cell membrane integrity, altering permeability and inhibiting spore germination and mycelial growth. In addition, it is known to induce natural defense responses in fruits and vegetables by activating defense-related enzymes and strengthening cell walls. This dual action-direct inhibition of pathogens and stimulation of host resistance-makes chitosan highly effective against common postharvest pathogens such as Colletotrichum, Fusarium, Alternaria and Aspergillus species.

Role in Quality Preservation

Apart from disease suppression, chitosan plays a crucial role in maintaining postharvest quality. When applied as a thin edible coating, it forms a semi-permeable film on the surface of fruits and vegetables. This coating reduces respiration rate and ethylene production,

Figure.A,B – Chitosan – A natural biopolymer used as an eco-friendly postharvest treatment

thereby delaying ripening and senescence. It also minimizes physiological weight loss by reducing moisture evaporation and helps retain firmness, colour and texture. Several studies have reported better retention of nutritional components, including ascorbic acid and antioxidants, in chitosan-treated produce.

Application in Fruits and Vegetables

Chitosan has shown encouraging results in a wide range of fruits and vegetables such as banana, mango, papaya, apple, citrus, grape, tomato, chilli and cucumber. The methods of application are simple and farmer-friendly, commonly involving dipping or spraying at low concentrations. Since only small quantities are required, chitosan treatments are cost-effective and suitable for adoption at both farm and market levels.

Compatibility with Integrated Postharvest Approaches

An important strength of chitosan is its compatibility with other eco-friendly postharvest methods. It can be effectively combined with essential oils, plant extracts, biocontrol agents and edible waxes to enhance disease control and extend shelf life. Such integrated approaches reduce dependence on synthetic fungicides and help meet the growing consumer demand for residue-free fruits and vegetables.

Environmental and Consumer Safety

From an environmental and consumer safety perspective, chitosan is considered highly safe and sustainable. Being a naturally derived biopolymer, it is biodegradable and breaks down easily in the environment without causing pollution. Unlike synthetic chemical fungicides, chitosan does not accumulate in soil, water or food chains and leaves no harmful chemical residues on fruits and vegetables.

The use of chitosan fits well with the principles of organic farming and sustainable agriculture, where emphasis is placed on natural, eco-friendly inputs. Chitosan is non-toxic to humans and safe for handlers, farmers and consumers, even when used repeatedly. Since it is applied as a thin edible coating, it poses no risk to human health and does not affect the taste or safety of the produce.

Because of these advantages, chitosan-based postharvest treatments are environmentally benign, consumer-safe and suitable for long-term use, offering a reliable alternative to chemical fungicides in postharvest disease management.

Conclusion

Chitosan emerges as a promising biopolymer for postharvest disease management and quality preservation in fruits and vegetables. Its antifungal properties, film-forming ability, safety and eco-friendly nature make it a viable alternative to chemical fungicides. Wider awareness, field-level validation and commercialization of chitosan-based technologies can help farmers, traders and consumers benefit from a sustainable and safe postharvest management strategy. ■

Microbiomes in Agriculture

Tiny Tools Shaping the Future of Farming

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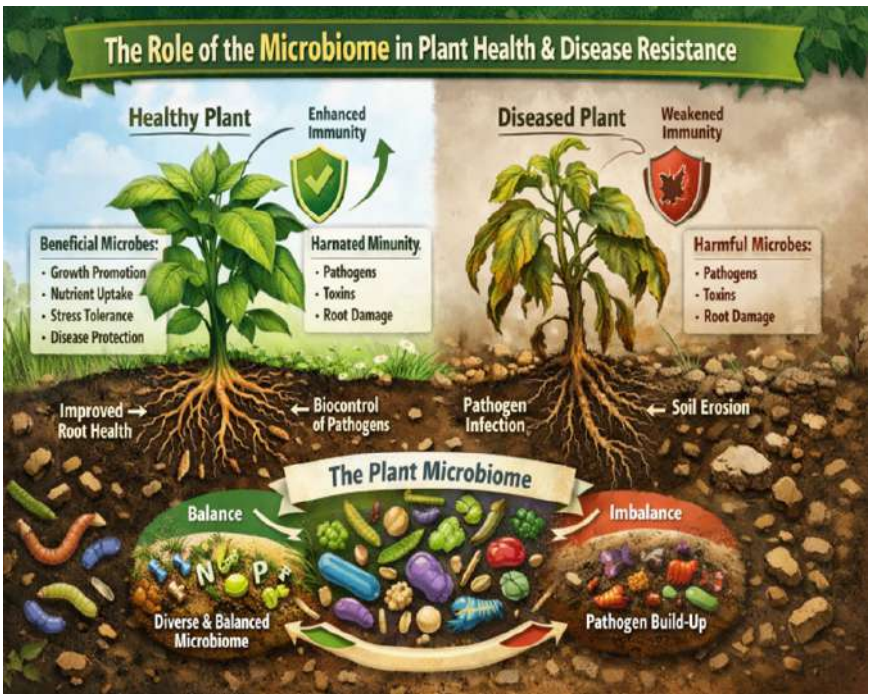
What is a plant microbiome?

Plants are not solitary organisms; they live in close association with a vast and diverse community of microorganisms. These plant-associated microbes include bacteria, fungi, protists, nematodes, and viruses that colonize all accessible plant tissues (Trivedi et. al., 2022). Many of these microbes are found in the soil surrounding plant roots, on leaf surfaces, and within plant tissues themselves. Collectively, these microbial communities are known as the plant microbiome (Munir et. al., 2022). Plants interact with highly diverse microbiota inhabiting different ecological niches, including the rhizosphere (soil closely associated with roots), the plant episphere such as the rhizoplane and phyllosphere, and the endosphere, which includes internal plant tissues (Compant et. al., 2025). Among these, the rhizosphere microbiome plays a particularly critical role, as it forms a dynamic interface where intense interactions occur between plant roots and soil microorganisms. These interactions are essential for plant nutrition, growth, and health. However, the composition and function of these microbial communities are strongly influenced by a combination of biotic and abiotic factors, such as pathogens, soil type, climate, and agricultural practices (Afridi et. al., 2024). The microbiome exerts a strong influence on its host plant, shaping its development, stress tolerance, and overall fitness. With increasing evidence supporting microbial inheritance, the traditional concept of plant evolutionary potential is being expanded to include not just the plant genome, but also its associated microbiome. In this context, the plant and its microbiome together can be viewed as a single functional unit, referred to as a meta-organism or holobiont (Vandenkoornhuyse et. al., 2015; Berg et. al., 2021). Seeds play a unique and crucial role in this inheritance process. By linking successive plant generations, seeds act as a bottleneck that determines which microorganisms are passed on. Plant microbiome assembly often begins with seeds, which serve as important reservoirs of microorganisms (Berg et. al., 2009; Berg et. al., 2021). The process of plant microbial inheritance occurs in three main stages: transfer from the parent plant to the seed, persistence during seed dormancy, and transmission from the seed to the emerging seedling. Each of these stages is governed by distinct biological processes (Abdelfattah et. al., 2023).

Boosting Crop Growth Naturally through the Plant Microbiome

Plant-associated microbiomes play essential roles in enhancing plant nutrition and protecting plants from both biotic and abiotic stresses. These diverse microbial communities perform multiple beneficial functions, including nitrogen fixation, nutrient

solubilization, suppression of devastating plant pathogens, and the production of important bioactive compounds such as phytohormones (indole-3-acetic acid, auxins, gibberellins, abscisic acid), aminocyclopropane-1-carboxylate (ACC) deaminase, and antibiotics. In addition, they stimulate induced resistance against pathogens and support the proliferation of other beneficial microorganisms in the plant environment (Afridi et. al., 2022). Through these mechanisms, plant-associated microbes strongly influence plant physiology, growth, and overall development.The composition and function of plant microbial communities are largely shaped by environmental factors, which determine how plants interact with beneficial microorganisms. One of the most important and well-studied examples of such interactions is mycorrhiza, a symbiotic association between fungi and vascular plants. Among these, arbuscular mycorrhizal fungi (AMFs) are obligate symbionts that associate with most terrestrial plants, including halophytes. AMFs colonize plant roots by forming specialized structures such as vesicles and hyphae and can also sporulate in the rhizosphere.The extensive hyphal network formed by AMFs greatly increases the soil surface area accessible to plant roots, leading to improved nutrient uptake and enhanced plant growth. Through efficient translocation of nutrients, AMFs contribute significantly to plant nutrition while also improving soil structure, soil quality, and overall plant health. Beyond nutrition, AMFs employ multiple mechanisms to alleviate abiotic stresses. These include enhanced mineral acquisition, improved water uptake, maintenance of ionic homeostasis, synthesis of phytohormones, increased photosynthetic activity, and elevated production of



antioxidant enzymes.Under saline conditions, excessive concentrations of sodium (Na^+) and chloride (Cl^-) ions often compete with the uptake and translocation of essential nutrients such as calcium (Ca^{2+}), phosphorus (P), potassium (K^+), and magnesium (Mg^{2+}). This ionic imbalance alters soil solution chemistry, disrupts plant nutrient ratios, and ultimately leads to reduced plant growth and biomass. However, AMF–plant symbiosis has been shown to mitigate these adverse effects. Improved salinity tolerance through AMF associations has been reported in several crops, including wheat, alfalfa, tomato, and maize (Munir et. al., 2022).

Natural protection against plant diseases

Comparable improvements in plant health can be achieved through a range of microbiome-based strategies. Among these, plant growth–promoting rhizobacteria (PGPR) function much like probiotics for plant roots, supporting growth and enhancing resilience. Similarly, specific prebiotic substrates and soil additives help selectively enrich beneficial microbial communities. Interestingly, healthy plants are often found growing alongside diseased ones, even when they are genetically susceptible to the same pathogen, highlighting the protective influence of the surrounding microbiome (Pereira et. al., 2023). Together, these approaches bring about targeted changes in the plant-associated microbiome and are commonly applied as soil amendments in sustainable agriculture (Afridi et. al., 2022).

The plant microbiome plays a multifaceted role in defending plants against pathogen attacks through several complementary mechanisms. Beneficial microbes can activate plant immune responses, trigger induced systemic resistance (ISR), and strengthen plant cell walls through callose deposition. In addition, these microbes actively produce a diverse array of antimicrobial substances that suppress pathogens. These include well-known compounds such as 2,4-diacetylphloroglucinol,

proteases, chitinases, bacteriocins, and siderophores, as well as antimicrobial lipopeptides like iturin A, bacillomycin D, and mycosubtilin. Volatile compounds released by beneficial microbes further contribute to inhibiting pathogen growth and spread, reinforcing the microbiome's role as a natural line of plant defense (Ali et. al., 2023).

Helping plants tolerate stress

Plantmicrobe interactions are strongly influenced by environmental conditions and play a key role in enhancing plant resilience to environmental stresses (Trivedi et. al., 2022). Among the most important beneficial microorganisms involved in stress mitigation are plant-growth-promoting rhizobacteria (PGPRs) and plant-growth-promoting fungi (PGPFs). These microorganisms help plants cope with abiotic stresses by employing multiple strategies, including the production of phytohormones, reduction of ethylene levels, upregulation of dehydration-responsive pathways, and induction of genes encoding antioxidant enzymes.Many root-associated bacteria secrete phytohormones that alleviate stress conditions such as salinity and promote seedling growth. For example, plant-growth-promoting bacteria such as Pseudomonas spp. and Bacillus spp. enhance plant growth under stressed conditions through the secretion of indole-3-acetic acid (IAA) and siderophores. Lowered ethylene levels in plant tissues further stimulate root elongation and development, ultimately contributing to improved plant health.

To survive under suboptimal environmental conditions, plants have evolved a range of adaptive mechanisms, many of which depend on close associations with soil and root-associated microorganisms. Plant survival largely depends on how effectively plants respond to biotic and abiotic stresses, and this response is significantly influenced by interactions with the root microbiome. A wide range of microorganisms including bacteria, fungi, archaea, and oomycetes—colonize plant roots, with most of these microbes being recruited from the surrounding soil microbial community.The composition of root-associated microbial communities is shaped by both the soil microbial pool and distinct root compartments, namely the rhizosphere, rhizoplane, and root endosphere. Soil factors such as pH and the availability of key nutrients, including phosphorus (P), carbon (C), and nitrogen (N), play major roles in determining the structure of soil bacterial and fungal communities. In turn, plants actively influence the composition of the rhizosphere microbiome through the release of organic compounds, mucilage, microbe-signaling molecules, and sloughed root border cells. Together, these components create nutrient-rich conditions that favor microbial growth and selectively recruit beneficial microbes to the rhizosphere. Host plant genetic factors further regulate microbial recruitment by activating microbe-signaling pathways and plant immune responses. This selective process enables soil microbes to attach to the rhizoplane and subsequently enter the root endosphere, where more intimate plant–microbe interactions occur (Munir et. al., 2022).

Microbiome based products in the field

Manipulating the soil microbiome to enhance plant growth and protection has long been recognized as a promising approach in agriculture. The soil microbiome engages in complex interactions with plants and their root systems, contributing to nutrient availability, removal of contaminants, and stimulation of plant growth (Afridi et. al., 2022). In recent years, it has been widely assumed that crop productivity can be improved through modern strategies that involve the use of beneficial microorganisms. These microbes enhance crop performance by stimulating phytohormone production, facilitating nitrogen fixation, and increasing resistance to both abiotic and biotic stresses.Detailed research on beneficial microorganisms has enabled the development of targeted microbial formulations and consortia that can improve plant productivity in a cost-effective and environmentally friendly manner (Munir et. al., 2022). Consequently, harnessing the potential of the phytomicrobiome for sustainable agriculture has gained significant attention, with this research area expanding rapidly (Lakshmanan et al., 2014). Despite these advances, crops continue to face numerous challenges throughout their life cycle, including biotic stresses caused by pathogens and abiotic stresses resulting from fluctuating environmental conditions. More recently, the introduction of beneficial microbes or engineered microbial communities has emerged as a widely adopted strategy for microbiome manipulation. However, the successful application of these approaches under field conditions remains challenging. Factors such as competition among native and introduced microbial populations, difficulties in establishing stable microbial communities, and the increasing impacts of global climate change can limit their effectiveness (Afridi et. al., 2024).

Encouragingly, studies have shown that growing a susceptible crop variety in soil previously cultivated with a resistant variety can slow the progression of bacterial wilt disease. Such findings provide compelling evidence supporting rhizosphere microbiome transplants (RMT) as a plausible and innovative approach for protecting plants against pathogen infections (Jiang et. al., 2022).

Conclusion

In conclusion, plants should be viewed not as independent entities but as dynamic biological systems intricately linked to diverse microbial communities that influence every stage of plant growth and development. The plant microbiome plays a pivotal role in improving nutrient acquisition, enhancing tolerance to biotic and abiotic stresses, and protecting crops from pathogens through a wide range of biological mechanisms. Growing evidence suggests that strategic manipulation of these microbial communitiesthrough microbial inoculants, soil amendments, and microbiome transplantscan offer sustainable and cost-effective alternatives to conventional agricultural practices. Although challenges remain in ensuring consistency and stability of microbiome-based interventions under field conditions, ongoing advances in microbial ecology, genomics, and climate-resilient agriculture continue to strengthen their practical potential. Ultimately, harnessing the plant microbiome represents a promising pathway toward environmentally friendly farming systems that support crop productivity, soil health, and long-term food security in a changing climate.

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MARCH 2026
VOLUME 13 ISSUE 10

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