DEPARTMENT OF AGRICULTURE DEVELOPMENT
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KERALA KARSHAKAN

E-JOURNAL

THE FIRST ENGLISH FARM JOURNAL FROM
THE HOUSE OF KERALA KARSHAKAN

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SUPER FOODS FOR THE FUTURE

Nutrition, resilience, and sustainability
for a healthier tomorrow

INSIDE

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Editorial

Super Foods for the Future

Nutrition, resilience, and sustainability for a healthier tomorrow.

The future of agriculture is not defined by quantity alone; it is increasingly shaped by the quality of food we produce and consume. As the world faces the dual challenges of malnutrition and climate change, attention is shifting towards crops and plant resources that offer superior nutrition, adaptability, and health benefits. Often referred to as "super foods," these resources have the potential to strengthen food security while supporting healthier lifestyles. From nutrient-rich grains and pulses to medicinal plants and value-added natural products, the search for future foods is gradually reshaping agricultural priorities.

India's rich biodiversity and traditional knowledge systems provide a strong foundation for this transition. Many crops that have long been part of local food cultures are now gaining renewed attention for their nutritional, medicinal, and functional properties. At a time when consumers are becoming increasingly conscious of health and wellness, agriculture has an important

role to play in connecting production with nutrition and preventive healthcare.

Equally important is the need to utilise agricultural resources more efficiently. Sustainable food systems require not only the cultivation of nutritious crops but also the effective use of by-products, reduction of waste, and promotion of value addition. Scientific research continues to reveal new possibilities hidden within traditional crops, opening avenues for innovation, entrepreneurship, and improved farmer income.

This issue focuses on the theme "**Super Foods for the Future**", exploring crops and plant resources that can contribute to a healthier and more sustainable world. We invite readers to explore the articles that follow and discover how nutrition, science, and sustainability can come together to shape the future of agriculture. When food is viewed not merely as a commodity but as a pathway to health and resilience, agriculture becomes a powerful force for human well-being and sustainable development.

Editor

Goodness is Black

A Superfood for the Future?

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White rice, the most widely grown and consumed food in our country, comes with its own predicaments. Apart from its massive production and reluctance from the consumer to change his preferences, people still have to think twice before eating their favorite food. Consumption of white rice in large quantities or over long periods of time, poses the threat of various health problems including malnutrition, anemia and aggravated diabetes. But what if we could combine the familiarity of rice with improved nutritional value to aid this deeprooted Indian habit? Black rice (Oryza sativa_L. indica) is a very relevant upcoming solution to these problems. While adding a nutty flavor to the regular taste of white rice, black rice can be a multinutrional food which provides numerous health benefits as well. It is also becoming increasingly popular for its various cosmetic, nutraceutical and pharmaceutical applications. Cultivated for centuries in the Asian continent and reserved only for the consumption of royals and elites, black rice now has the potential to serve as an alternative for regular white rice for the increasingly health conscious consumer in the modern age. It is not without reason why this rice is called “Chakhao” meaning ‘delicious rice’ by the Meitei farmers of Manipur.

History

Black rice has been consumed for centuries in Asian countries such as China, Korea, and Japan and is known for its higher antioxidant activity compared to white rice. During the imperial period in China and Indonesia, it was reserved exclusively for royalty and elite groups, as it was believed to promote longevity and good health. Because of its rarity and high value, it was often called forbidden rice, imperial rice, king’s rice, or purple rice. Today, black rice is cultivated in several countries. China holds the largest share of black rice resources (62%), followed by Sri Lanka, Indonesia, India, Bangladesh, and Malaysia, with about 200 varieties developed, including 52 high-yielding types.

Varieties of Black rice

1. **Black Japonica:** A mix of short and medium grains with an earthy, slightly sweet, and spicy flavor.
2. **Black Thai Jasmine:** A fragrant, medium-grain aromatic rice variety.
3. **Black Glutinous Rice:** A sticky, short-grain rice widely used in Asian desserts.
4. **Black Italian Rice:** A long-grain aromatic variety commonly used in risotto.
5. **Chak-Hao (Manipur):** An aromatic, glutinous rice also called “Forbidden Rice”. Types include Poireiton (deep purple) and Amubi (black/ red).
6. **Karuppu Kavuni (Tamil Nadu):** A traditional, highly nutritious black rice commonly used in sweet dishes and known for health benefits.

Nutritional Composition Table

Component	Percentage	Notes
Carbohydrates	~70% – 76%	Primarily starch
Protein	~8.5% – 11.5%	Very high compared to other rice types
Fiber	~2.0% – 4.9%	Mostly insoluble, aiding digestion
Fat	~1.5% – 3.0%	Includes beneficial unsaturated fats
Ash/Minerals	~1.5% – 2.0%	Rich in Iron, Zinc, Magnesium
Moisture	~10% – 12%	Typical moisture level

7. **Kalabhat (West Bengal):** A mildly fragrant variety with dry grains that range from dark brown to black.

Nutritional composition

Black rice is a good source of vitamins, amino acids and bioactive compounds viz flavanoids, phenolic compounds, minerals, γ–tocopherol, γ- tocopherol, γ–oryzanols etc. It has health advantages, and use in the food industry because it is gluten-free and packed with antioxidants. It gets its name ‘black rice’ due to the presence of anthocyanin pigments (cyanidin-3-glucoside and peonidin-3-glucoside) in the bran which makes black rice a good source of antioxidants. Black rice is also a non-glutenous food that is a good source of fibre. Thus, black rice has a wealth of health benefits. Black rice has promising positive effects against constipation, carcinogenesis, tumor, coronary heart disease, atherosclerosis, inflammations, nephrological disorders, type 2 diabetes, anemia, hyperglycemia, hypertension, obesity etc.Black rice varieties are exceptionally rich in protein and fibre while red rice is known for its high iron and zinc content.

Profitability

High Market Value: Black rice is considered a premium rice variety because of its nutritional and medicinal properties. It

> Black rice has been consumed for centuries in Asian countries such as China, Korea, and Japan and is known for its higher antioxidant activity compared to white rice.

usually sells at a higher price than ordinary white rice, increasing farmers' income.The price of black rice in India typically range between 200₹-400₹

Nutritional and Health Benefits: It is rich in antioxidants (anthocyanins), iron, protein, and fiber. Due to its health benefits, demand is increasing among health-conscious consumers.

Value-Added Products: Black rice is used to make various products such as noodles, bread, cakes, desserts, beverages, and snacks. These value-added products create more business opportunities.

Export Potential: Black rice has a growing demand in international markets because it is considered a "superfood." Countries export it to earn foreign exchange.

Supports Small Farmers: Traditional varieties like Chak-Hao and Karuppu Kavuni are cultivated by small farmers. Growing these specialty rice varieties can improve rural livelihoods.

Cultural and Traditional Importance: In some regions like Manipur and Tamil Nadu, black rice is used in traditional dishes and festivals, which also supports local markets and tourism.

Cultivation aspects

Black rice is a high-value, nutrient-dense, and often organic crop requiring warm climates full sun, and 3–6 months to mature. Primarily cultivated in Northeast India (especially Manipur) using manual labor, it thrives with consistent watering and organic inputs, though it has lower yields compared to white rice.

Growing Conditions: Thrives in warm, sunny climates with a long growing season. It is suitable for areas with consistent water supply.

Methods: Commonly cultivated through the SRI (System of Rice Intensification) method, which uses about 5 kg of seeds per acre. Other methods include transplanting 25-30 day old seedlings or direct sowing.

Soil and Nutrition: Prefers nutrient-rich soil; incorporating compost is recommended.

Spacing: Proper spacing (around 25 cm x 25 cm) is crucial to prevent competition for nutrients.

Organic Practices: Often cultivated without synthetic chemicals, relying on natural manure.

Water Management: Requires consistent, adequate, irrigation, especially during critical growth stages, but waterlogging should be managed.

Harvesting: Yields typically lower than white rice.

Why is this not famous in Kerala?

Black rice is not widely cultivated in Kerala due to several agro-ecological and socio-economic factors. Varieties such as Chak-Hao are indigenous to North-East India and are better suited to climatic conditions different from Kerala's humid tropical climate. Black rice also has relatively low yields and higher production risks compared to commonly cultivated white or red rice varieties. Additionally, rice cultivation in Kerala has declined significantly due to land conversion, labour shortages, and high production costs. Farmers also prefer traditional varieties like Pokkali and Wayanad landraces that are well adapted to local soils and ecosystems, while black rice often faces germination and water-management challenges under Kerala conditions.

Value added Products

Black rice is recognized for its distinctive purple–black colour and is widely utilized in the preparation of desserts in many parts of the world. It is commonly used to prepare food products such as porridge, black rice cakes, sushi, and puddings, particularly in Southeast Asian countries. In addition, black rice is processed into various value-added products including pasta, noodles, biscuits, cookies, bread, chips, and wine. The extract of black rice is also used as a natural food colouring agent and serves as a safer alternative to synthetic food colours in beverages and other food products.

Challenges in cultivation

Utilization of black rice in India is still limited, and its potential as a food product has not been fully explored.

The potential of black rice has not yet been optimally utilized, which acts as a limiting factor for improving its productivity and cultivation. Black rice is less preferred by farmers due to certain undesirable traits such as low yield, photoperiod sensitivity, longer vegetative phase, and tall plant stature, which often leads to lodging.

Lower productivity and higher market price reduce the accessibility of nutrient-rich black rice for the common population.

Conclusion

Even though it will take a long time before the real benefits of black rice are fully realized and widely accepted, there is no doubt that it will increasingly find its place in the diet charts and plans of the future. People are becoming increasingly health-conscious, and it is only a matter of time before this amazing food crop develops an ever-growing consumer base. Farmers can definitely benefit from investing in black rice cultivation, especially in urban and nutritionally conscious markets. Subsequently, more research needs to be conducted to improve desirable qualities in the crop in order to support sustainable farming practices and enhance marketability. Overall, it can be safely said that both farmers and consumers alike should keep an eye on this superfood of the future

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Green gram
a potential crop for Kerala

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Green gram is one of the rich source of vegetable protein. It is also known as golden gram, chickasaw pea, mung, mungo, and moong. The word "mung" is derived from the Sanskrit word "mudga". Green gram is originated in the Indian subcontinent and India is the major green gram producer in the world. Green gram is one of the major pulse crop of the country after chickpea and pigeon pea. It is cultivated in 3.55 million ha with a total production of 3.10 million tonnes. Major green gram growing states are Rajasthan, Karnataka, Maharashtra, and Madhya Pradesh.

Cultivation practices

Green gram can be cultivated as a pure crop in rice fallows or as an intercrop in coconut gardens or as a mixed crop with tapioca, colocasia, yam, and banana.

When majority of pods turns yellow to black, entire plants will be uprooted and spread

Co 8

Virat

A brief account of important varieties is furnished below

Variety	Crop duration (days)	Yield in kg/Ha	Remarks
TM 96-2	65-70	900-1000	Resistance against powdery mildew disease
CO 8	60 - 65	1000-1200	Good cooking quality. Moderately resistant to yellow mosaic disease and stem necrosis
IPM 02-14 (Shreya)	62-70	1100-1200	Resistance to mung bean yellow mosaic virus
Virat	52-56	1000-1100	Variety with short duration. Resistant to Mung bean yellow mosaic virus. Recommended in Tamil Nadu. Yield is less in Kerala condition

(Ref: Project Coordinator's Report, AICRP on MULLaRP , ICAR, IIPR, Kanpur. 2017-18 and 2020, ii) www.seednet.gov.in)

The fertilizer schedule for cultivation of one acre is furnished below

Day	Stage	Agronomic operations for one acre
Day 1	First plough	Add lime @ 100 kg
Day 14	Last plough	Add 8.5 kg urea, 60 kg rock phosphate and 20 kg potash
Day 15	Sowing	Dibbling seeds at a spacing of 30 x 10 cm. If broadcasting, use 10 kg seeds for pure crop and 2.5 kg seeds for mixed crop
Day 30	Two-three true leaf stage	Foliar spray of urea @ 2 %
Day 45	Starting of accessory shoots	Foliar spray of urea @ 2 %

on threshing yard. Seeds are extracted by beating pods with sticks and sundried to reduce moisture content.

Grading and Uses

Green gram could be used as whole seeds or dal by splitting the seeds. The grade standards are specified for green gram whole, split and split (dehusked) by the Directorate of Marketing and Inspection as General, Standard and Special, in the increasing order of quality and price.

Many recipes call for the use of fermented beans and germinated seeds as an ingredient. Fresh, just sprouted seeds can be used as a salad topping. Typically, mung bean sprouts are picked after a few days of germination and consumed raw or cooked in sandwiches, stir-fries, and other dishes.

Nutritional importance

Seeds have 25-28% protein. Significant amount of calcium, magnesium, iron, phosphorus, potassium, sodium, zinc, copper; vitamins such as A and C; and B complex vitamins like thiamine, riboflavin, niacin, pantothenic acid, vitamin B6 and folate are also present in green gram. In contrast to other pulses, high digestibility and less flatulence make it a healthy food option for elderly people, babies, and those recovering from illness.

Conclusion

High nutritional value, short duration, drought tolerance, nitrogen fixing ability and possibility of raising as a rainfed crop in marginal lands make green gram as a suitable alternative in various cropping systems. Even though Kerala has huge demand for green gram, its production in the state is meagre. Green gram cultivation has high potential in rice fallows and coconut plantations as pure and intercrop, respectively. As the paddy fields are situated below mean sea level, green gram cultivation in rice fallows is under the risk of flash floods. Kerala Agricultural University has started research to identify genotypes tolerant to flash floods. During intercropping, even though yield is compromised with respect to pure crop, soil enrichment will be an added advantage. ■

Turmeric Leaf Essential Oil

A New Value Chain for Spice Processors

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Turmeric cultivation in India is largely centred on the rhizome, which serves as the commercial product for spice, colouring and processing industries. Yet, alongside the harvested rhizomes, the crop also generates a substantial quantity of leaf and pseudostem biomass, much of which remains outside the commercial value chain. In several cultivars, fresh turmeric leaves alone may account for 6–10 tonnes of biomass per hectare, but this material is usually left in the field after harvest or incorporated back into the soil.

Recent attention to natural bioactives and plant-derived functional ingredients has begun to shift the way such biomass is viewed. Turmeric leaves are now

being recognised as a potential source of essential oil rich in bioactive terpenoid compounds, with relevance to food, agriculture and allied sectors. Through suitable extraction methods such as steam distillation or hydrodistillation, this underutilised biomass can be converted into a high-value product with applications ranging from food preservation and storage protection to biodegradable packaging and crop protection. In this context, turmeric leaf waste offers a practical opportunity for value addition, improved resource use and enterprise diversification within the spice sector.

Bioactives in turmeric leaves

Turmeric leaves are not merely field residues; they are a natural reservoir of volatile bioactive compounds. Much of their characteristic aroma and functional value comes from monoterpenes and oxygenated monoterpenes, compounds that are increasingly recognised for their antimicrobial, antifungal and insect-repellent properties. The composition of these volatiles is not fixed and may vary with cultivar, growing region and leaf maturity. For example, turmeric grown in southern India has often been reported to contain relatively higher 1,8-cineole, while certain landraces show greater proportions of α-phellandrene. A summary of the major constituents reported in turmeric leaf essential oil is presented in Table 1.

What makes these compounds particularly valuable is that they occur only in small quantities within the fresh leaf, yet they account for much of its

Table 1. Major bioactive constituents in turmeric leaf essential oil

Compound	Composition (%)	Functional property	Potential use	Benefits
α-Phellandrene	20–40	Insect-repellent, fumigant activity	Stored grain protection, botanical pesticides	Indicates strong potential for natural pest control products
1,8-Cineole (Eucalyptol)	15–30	Antimicrobial, antifungal, aroma-active	Food preservation, herbal formulations, coatings	Useful for reducing spoilage and improving product stability
α-Pinene	5–15	Antibacterial, insecticidal	Bio-preservatives, crop protection formulations	Supports dual role in food safety and pest control
γ-Terpinene	3–10	Antioxidant activity	Food systems, packaging applications	Helps delay oxidation and extend shelf life
p-Cymene	2–8	Antimicrobial, preservative synergy	Natural preservative blends, food coatings	Enhances overall effectiveness of essential oil formulations

functional potential. When leaves are simply dried and powdered, a significant portion of these volatile molecules may be lost during drying, handling and storage. Essential oil extraction, on the other hand, helps recover and concentrate these compounds into a compact, stable and marketable form. In practical terms, this means that a bulky agricultural residue can be converted into a small but high-value product with direct relevance to food preservation, storage protection and agricultural applications.

Hydrodistillation: Essential Oil Recovery Technology

Essential oil from turmeric leaves is commonly extracted using steam distillation or hydrodistillation, techniques widely employed for aromatic crops. In a typical process, freshly harvested leaves are collected, loaded into a distillation vessel, and exposed to steam for about 3–4 hours. The vapour carrying the volatile compounds is then condensed, and the oil is separated from water using a Florentine separator, after which it is stored in airtight containers. A typical hydrodistillation process is illustrated in Figure 1.

Reported oil recovery from turmeric leaves is generally around 0.3–0.8% on a fresh weight basis, which is roughly equivalent to about 2% on a dry weight basis, depending on moisture content, leaf maturity and distillation efficiency. In practical terms, 1 tonne of fresh turmeric leaves can yield around 3–8 kg of essential oil. A 200–300 kg batch distillation unit can therefore produce approximately 0.6–2 kg of oil per batch, making the technology suitable for small and medium-scale agro-processing enterprises.

To improve recovery beyond conventional distillation, pretreatments such as ultrasound, microwave heating and enzyme-assisted hydrodistillation can be employed. These methods help disrupt leaf tissues and glandular structures more effectively, allowing volatile compounds to be released more efficiently during distillation and thereby improving oil yield and process efficiency.

Applications of Turmeric Leaf Essential Oil

Turmeric leaf essential oil is gaining attention across several agro-food applications owing to its terpene-rich composition and diverse bioactive properties. A few key areas where its functional potential is being explored are outlined below.

Antimicrobial applications in food systems

Conventional food preservation has long relied on synthetic chemical preservatives to control microbial spoilage and extend shelf life. However, increasing concerns over chemical residues, consumer health perception, and clean-label preferences have accelerated interest in plant-derived alternatives. In this context, turmeric leaf essential oil is gaining attention as a potential natural preservative for food systems.

Studies have shown that turmeric leaf essential oil can

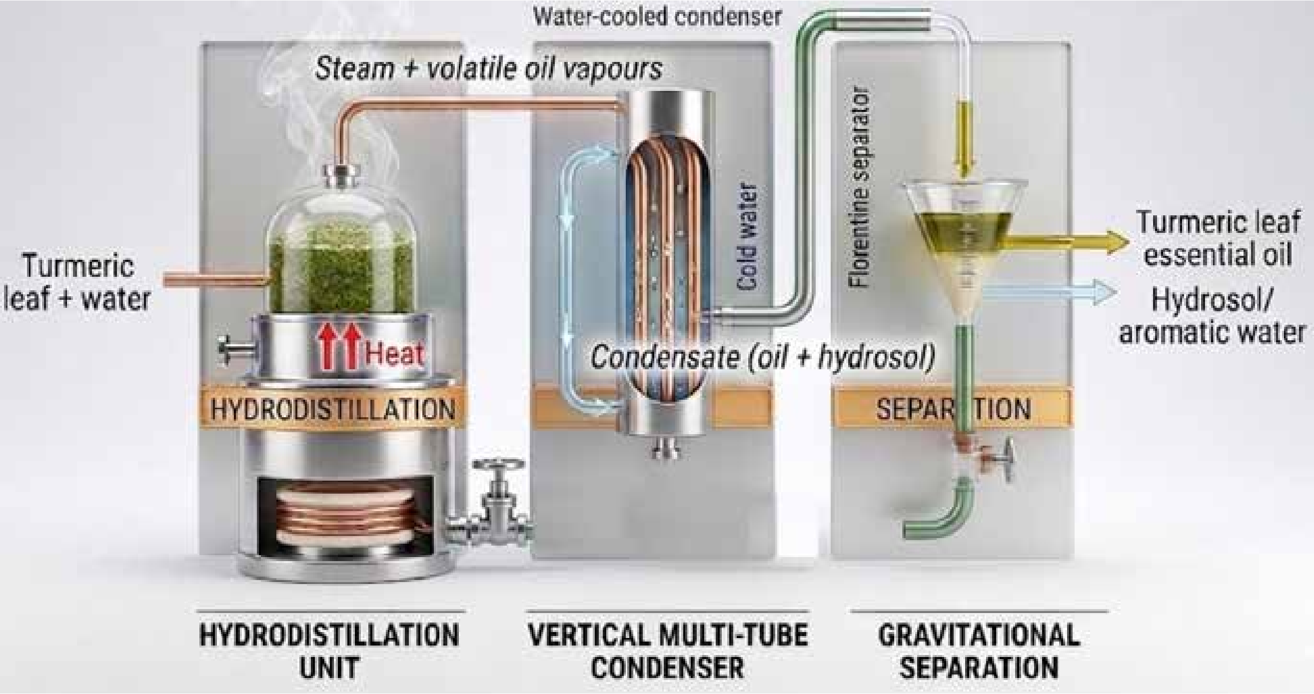

Figure 1. Schematic diagram of a hydrodistillation unit for turmeric leaf essential oil

inhibit several microorganisms associated with food spoilage and contamination, including Aspergillus flavus, Penicillium spp., Escherichia coli, and Staphylococcus aureus. Compounds such as 1,8-cineole and α-pinene can disrupt microbial cell membranes, leading to leakage of intracellular components and suppression of growth. Owing to these properties, turmeric leaf oil is being explored for applications such as antimicrobial edible coatings, bioactive additives in bakery products, and protective treatments for fish and meat during storage. Its volatile and biodegradable nature further supports its suitability as a natural alternative to conventional food preservatives.

Protection against stored grain pests

Stored grains are conventionally protected using synthetic fumigants and contact insecticides to minimize post-harvest losses during storage. Although effective, their repeated use has raised concerns related to chemical residues, pest resistance, worker safety and environmental persistence. This has encouraged renewed interest in plant-derived volatiles as safer alternatives for grain protection.

Essential oil from turmeric leaves is commonly extracted using steam distillation or hydrodistillation, techniques widely employed for aromatic crops.

Post-harvest insect infestation continues to cause significant losses in stored grains, with estimates in India suggesting 5–10% losses under unfavourable storage conditions. In this context, turmeric leaf essential oil has shown promising fumigant and repellent activity against common storage pests such as Sitophilus oryzae (rice weevil), Tribolium castaneum (red flour beetle), and Callosobruchus maculatus (pulse beetle). The terpene-rich volatile compounds present in the oil are believed to interfere with insect nervous and respiratory systems, resulting in repellency or mortality. Because these compounds degrade relatively quickly and leave minimal chemical residues, turmeric leaf essential oil is increasingly being considered within integrated pest management (IPM) strategies as a safer alternative to conventional grain protectants.

Antioxidant activity of essential oils

Oxidative deterioration remains a major cause of quality loss in foods, particularly in products rich in lipids, pigments and aroma compounds. Although synthetic antioxidants such as BHA, BHT and TBHQ are commonly used to delay rancidity and oxidative spoilage, there is increasing interest in natural alternatives that can offer similar protection.

In this context, turmeric leaf essential oil has shown notable antioxidant potential, largely due to its bioactive terpenoids and related volatile constituents. Studies have reported appreciable free radical scavenging activity using assays such as DPPH, ABTS and FRAP, indicating its ability to neutralize reactive oxygen species. Compounds such as ar-turmerone, α-turmerone and β-turmerone, along with other sesquiterpenes and oxygenated volatiles, are believed to contribute to this activity by donating hydrogen atoms or electrons and thereby limiting oxidative damage. This antioxidant behaviour adds further value to turmeric leaf oil, particularly in applications related to food preservation and active packaging, where oxidative stability plays an important role in maintaining product quality.

Bioactive and Biodegradable Packaging

Growing concerns over plastic waste and food spoilage are driving the development of packaging materials that can do more than simply enclose the product. This has led to increasing interest in active and biodegradable packaging systems, where the packaging itself contributes to preservation.

Biopolymers such as chitosan, starch and gelatin are being widely investigated as sustainable alternatives to petroleum-based plastics. When natural essential oils are incorporated into these materials, they can provide antimicrobial and antioxidant functionality to the packaging system. Studies on essential oil–incorporated films have shown reduced microbial growth on packaged foods, improved shelf life of perishable products, and enhanced oxidative stability. Owing to its terpene-rich composition, turmeric leaf essential oil presents a promising bioactive additive for such systems, particularly when incorporated

into starch-based films derived from agricultural resources. This opens up opportunities for packaging solutions that are not only biodegradable, but also functionally active in maintaining food quality.

Value Chain from Turmeric Leaf Biomass

Conventional turmeric processing remains largely focused on rhizome operations, cleaning, boiling, drying, polishing and powder production, while the substantial leaf biomass generated during harvest is seldom utilised. This presents a clear opportunity for value addition. By integrating essential oil extraction from leaves into existing spice processing systems, what is currently treated as waste can be converted into a high-value co-product.

Several operational models can enable this integration within turmeric-growing regions:

- Spice processing units: Freshly harvested leaves can be directed to distillation units located within or near turmeric processing facilities.
- Farmer Producer Organisations (FPOs): Decentralised distillation systems can aggregate leaf biomass from multiple farms during the harvest season.
- Rural essential oil enterprises: Mobile or stationary distillation units can be operated close to turmeric cultivation clusters, reducing biomass transport costs.

From a commercial perspective, the opportunity is significant. Plant-derived essential oils used in flavour, fragrance, food preservation and botanical pesticide sectors typically command prices in the range of Rs. 3,000 to Rs. 12,000 per kg, depending on quality and end use. With an average recovery of around 5 kg of oil per tonne of fresh turmeric leaves, a modest unit processing 5 tonnes of leaves per day could potentially produce about 25 kg of essential oil daily.

In addition to oil recovery, the spent leaf biomass after distillation retains organic matter and can be returned to the field as compost, soil conditioner or mulch, supporting nutrient recycling. Such integration improves resource efficiency within turmeric production systems while creating an additional revenue stream.

There is also scope to further strengthen this value chain through process innovation. Industries already equipped with technologies such as ultrasound, pulsed electric field (PEF), microwave or enzyme-assisted systems may explore their use in enhancing essential oil recovery from turmeric leaves. Improved cell disruption and mass transfer in such systems can potentially increase extraction efficiency and overall process viability. By combining existing distillation infrastructure with emerging processing technologies, spice enterprises can move towards a more resilient, efficient and circular value chain, where both rhizomes and leaf biomass contribute meaningfully to economic returns.

Concluding remarks

Turmeric leaves, once considered a low-value agricultural residue, are now being recognised as a source of bioactive essential oils with significant functional and commercial potential. This shift in perspective highlights how underutilised biomass within spice production systems can be repositioned as a value-added resource.

At the same time, wider adoption will depend on addressing a few practical constraints. Variability in oil composition across cultivars and regions, the seasonal availability of leaf biomass, and the need for standardised extraction and quality control protocols remain important considerations. In addition, improving awareness among processors, farmer groups and entrepreneurs will be critical to translating this potential into practice.

With increasing demand for natural preservatives, plant-based crop protection solutions and sustainable packaging materials, turmeric leaf essential oil is well positioned to find a niche within the natural products sector. Its successful utilisation would not only create new opportunities for spice-based enterprises but also demonstrate how processing innovation can transform agricultural residues into commercially relevant bioactive products. ■

References available on request.

Bankakri

(Podophyllum hexandrum Royle)

An important endangered medicinal plant of Himalayan region

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Abstract

Bankakri (Podophyllum hexandrum Royle; family: Berberidaceae), a high-value medicinal plant endemic to the Himalayan region, holds significant importance in both traditional and modern pharmacopoeia. This review synthesizes current knowledge on its ethnobotany, phytochemistry, and conservation status to provide a comprehensive overview for researchers and conservationists. Traditionally known as Bankakri and revered in Ayurveda as 'Aindri', its rhizomes and roots have been extensively used to treat a wide array of ailments, from constipation and skin conditions to cancers and gynaecological disorders. Its modern therapeutic value is primarily derived from its rich concentration of bioactive lignans, notably podophyllotoxin, a precursor for the synthesis of critical anticancer drugs like

Fig.1: Freshly harvested fruits of Bankakri

etoposide and teniposide. The Indian variety of P. hexandrum contains a significantly higher yield of this compound compared to its American counterpart, P. peltatum. However, due to high medicinal and commercial demand, coupled with habitat fragmentation and inherent biological limitations, has led to severe over-exploitation, placing the species in an endangered category and at risk of extinction. This precarious status underscores the urgent need for robust conservation strategies, the development of sustainable cultivation practices, and targeted research to explore its full therapeutic potential.

Keywords

Podophyllum hexandrum, Germplasm, Ethnobotany, Podophyllotoxin, Medicinal plants, Conservation

1.0 Introduction

Podophyllum hexandrum Royle, commonly known as Bankakri or the Himalayan May apple, is a high-value medicinal plant endemic to the unique ecosystems of the Himalayan region. For centuries, it has been a cornerstone of indigenous medical systems, and its potent biochemical profile has secured its place in the development of modern pharmaceuticals. The strategic importance of this review lies in the intersection of the plant's immense therapeutic value and its precarious ecological standing. Extensive use in both traditional healing and contemporary oncology has driven demand, leading to overexploitation and placing wild populations under severe threat. A consolidated understanding of its botanical, chemical, and ecological characteristics is therefore essential to guide future research, sustainable utilization, and effective conservation efforts.

1.1 Nomenclature and Etymology

The scientific name P. hexandrum is descriptive of the plant's key physical features. The genus name Podophyllum is derived from the Greek words 'Podos' (a foot) and 'Phyllos' (leaf), an attribution to its large leaves, which resemble the shape of a duck's foot. The species name, hexandrum, refers to the presence of six petals and six stamens in its flower.

The plant is known by a variety of common names that reflect its broad geographical and cultural significance. In English, it is referred to as the Indian May apple or Himalayan May apple. Within the Ayurvedic tradition, it is known as Bantrapushi and, more significantly, as 'Aindri', a name that denotes its status as a sacred remedy. Across the Indian subcontinent, it is also called Bankakri and Giriparpat, while in Nepal it is known as Laghu Patra and in Pakistan as Kakhri.

1.2 Taxonomic Context

Podophyllum hexandrum belongs to the Berberidaceae family, a group of flowering plants that includes several other medicinally important species. Within the genus Podophyllum, its most notable relatives are the American May apple, P. peltatum.

Podophyllum aurantiocaule (E. Himalaya to China)

With its taxonomic identity established, a detailed examination of the plant's distinct botanical characteristics and ecological niche is essential for understanding its role in the Himalayan ecosystem.

2.0 Botanical Description and Geographic Distribution

A thorough understanding of the morphology and habitat of P. hexandrum is fundamental to its accurate identification in the wild, its successful cultivation, and the development of effective conservation strategies. These botanical details provide the foundational knowledge required for both scientific study and sustainable management of this valuable resource.

2.1 Morphology

P. hexandrum is a succulent, erect, and glabrous perennial herb that grows from a long, creeping, and knotty rhizome. The underground rhizome develops numerous adventitious roots that can extend up to 50 cm. The plant is described as an erect perennial herb reaching a height of 15–40 cm above the ground. The stem supports one or two simple leaves, which are palmate and can grow up to 25 cm in diameter. These leaves are deeply divided into three to five lobes with a toothed edge and are distinctively adorned with purple spots. They only unfurl completely after the flowering period. The flowers, which bloom in the spring, are cup-shaped, solitary, and typically white or pale pink. Following pollination, the flower develops into a fleshy, oval-shaped red berry, which serves as the fruit of the plant.

2.2 Habitat and Distribution

This species is indigenous to the Himalayan region, where it thrives in cold, shaded, and steep mountainous environments. It is typically found at high altitudes, with a documented range between 2200 to 4200 meters above sea level. Field observations have recorded its presence at even higher elevations, extending up to 4421 meters in the Gaigong area of North Sikkim. The plant's geographical distribution spans several countries across the Himalayas, including India, Bhutan, Pakistan, Afghanistan, Nepal, Tibet, and China.

Fig. 2: Natural habitats of Bankakri and variability in fruits

2.3 Distribution within India

Within India, P. hexandrum is concentrated in the high-altitude regions of the Himalayan states. Its distribution includes:

- **Primary States:** Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh.
- **Specific Locations in Himachal Pradesh:** It is found sporadically in the districts of Mandi, Rohru, Kangra, Chamba, and Lahaul-Spiti, as well as in the mountainous areas of Tosh, Malana, Kheer Ganga, and the Rohtang area in the Kullu district.
- **Specific Locations in Sikkim:** Its presence is predominantly noted in Yathang, Thangu Valley, and the Gaigong area of North Sikkim, at altitudes ranging from 3,000 to 4,500 meters.
- **Specific locations in Arunachal Pradesh:** Its distribution is recorded near Sella pass, Mago village side, Tale Valley, Pange and the Dichu Valley.
- **Specific locations in Uttarakhand:** Chamoli, Pithoragarh, Pauri Garhwal, Rudraprayag, Tehri Garhwal and Uttarkashi
- **Specific locations in Jammu & Kashmir and Ladakh:** Anantnag, Baramulla, Bandipur, Kargil, Leh, Pulwama and Srinagar

This distinct morphology and restricted high-altitude distribution have directly shaped the plant's historical and cultural relationship with Himalayan communities, a subject explored in the following ethnobotanical review.

3.0 Ethnobotanical Significance and Applications

Studying the ethnobotany of P. hexandrum reveals its deep integration into the cultural and medicinal practices of Himalayan communities. The plant has a long and revered history within traditional medicine systems like Ayurveda, where it is valued for its potent therapeutic properties. Its dual role as both a powerful remedy and a seasonal food source contributes significantly to its cultural value, but also to its ecological vulnerability as demand increases.

3.1 Traditional and Ethnomedicinal Uses

The applications of P. hexandrum in traditional medicine are extensive and varied, utilizing different parts of the plant to treat a wide range of conditions.

- **Ayurvedic System:**
  - In Ayurveda, it holds a sacred status and is referred to as 'Aindri'.
  - It is recognized and used as a potent hepatic stimulant and a purgative.
- **General Ailments Treated:**
  - The dried rhizomes and roots are used to treat colds, constipation, burning sensations, jaundice, dysentery, chronic hepatitis, rheumatism, and tumorous growths.
  - It is also applied for kidney and bladder issues.
  - A poultice made from the powdered rhizome is used

topically for skin conditions such as warts, ulcers, cuts, inflammation, insect bites, and other skin growths.

- o The mature fruits are traditionally used in the treatment of typhoid fever.

- **Specific Systemic Applications:**
  - o In the Tibetan medical system, it is employed to address various gynaecological disorders.
  - o It is also used in traditional practices against cancers affecting the brain, bladder, and lungs, including monocytoid leukemia.
- **Ethnoveterinary Uses:**
  - o Ground fruit mixed with buttermilk is administered to cattle to alleviate stomach bloating.
  - o A mixture of ground roots and wheat flour is given to animals to prevent nasal discharge.
  - o The Gaddis people use a decoction of the ground roots with sugar as a remedy for long-lasting constipation and to address stomach issues in animals.

3.2 Modern Allopathic and Pharmacological Applications

The therapeutic potential of P. hexandrum has been recognized and integrated into modern allopathic medicine. It is used in formulations to treat bacterial and viral infections, rheumatoid arthritis, and pyogenic skin infections. Its most significant modern application is in oncology, where it is used in treatments for lymphoma, Kaposi's sarcoma, and ovarian cancer. Furthermore, research has demonstrated its radioprotective properties; the plant's constituents can scavenge radiation-induced free radicals, offering protection against cellular and tissue damage.

3.3 Culinary Uses and Toxicity

Beyond its medicinal uses, P. hexandrum also has a place in the local cuisine of Himalayan regions, though its consumption requires careful consideration due to its toxicity.

- **Culinary Uses:** The ripe, deseeded fruits are edible and can be eaten raw or processed into jam, jelly, and desserts. Dried leaf powder is sometimes added in small quantities to dishes like pakoras for its medicinal benefits.
- **Toxicity Warning:** The plant contains toxic compounds, and consumption must be handled with caution. The immature fruit is toxic and acts as a laxative. While the leaves are considered consumable, they can also be toxic in excessive quantities and should only be used sparingly.

These diverse applications are a direct consequence of the plant's complex phytochemistry, which is responsible for its potent and varied biological effects.

4.0 Phytochemistry and Bioactive Constituents

The remarkable medicinal efficacy of P. hexandrum is directly attributable to its rich and complex phytochemical profile. The plant is a natural factory for a wide array of secondary metabolites, particularly lignans, which are the precursors to some of the most vital anticancer drugs used in modern medicine today. Understanding these compounds is key to unlocking the plant's full therapeutic potential.

4.1 Key Anticancer Lignans

P. hexandrum is a primary natural source of podophyllin resin and its chief constituent, podophyllotoxin. Podophyllin itself has a documented antimitotic effect, meaning it disrupts cell division and can inhibit tumor growth. Podophyllotoxin is a critical starting material for the semi-synthesis of modern chemotherapeutic agents, most notably etoposide and teniposide, which are widely used to treat various forms of cancer.

4.2 Comparative Podophyllotoxin Content

A key factor driving the commercial demand for P. hexandrum is its exceptionally high concentration of its primary bioactive compound. The Indian Himalayan species contains a significantly higher yield of podophyllotoxin, estimated at approximately 4% from its dried root. This is substantially greater than the concentration found in its American counterpart, P. peltatum, which contains only about 0.25% from its dried root.

4.3 Other Major Bioactive Compounds

In addition to podophyllotoxin, the rhizomes of P. hexandrum contain a diverse range of other bioactive compounds that contribute to its overall therapeutic profile.

4.4 Documented Pharmacological Activities

Scientific studies have documented a wide spectrum of

Compound Class	Examples
Lignans	4'-demethylpodophyllotoxin, podophyllotoxin-β-D-glucoside, deoxypodophyllotoxin, picropodophyllotoxin
Flavonoids	Quercetin, quercitrin, astragalin, rutin, kaempferol

biological activities associated with the plant's constituents, including antimicrobial, insecticidal, anti-inflammatory, antioxidant, anti-osteoporotic, and DNA-protecting effects.

The high concentration of these valuable chemical constituents has made the plant a target for extensive harvesting, which in turn has precipitated the significant threats and conservation challenges.

5.0 Conservation Status, Threats, and Propagation

The high medicinal and commercial value of P. hexandrum has created a critical conservation challenge. Intense demand for its rhizomes has led to severe over-exploitation of wild populations, pushing the species towards extinction. This situation makes the implementation of effective conservation measures and the development of sustainable propagation methods an urgent global priority.

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5.1 Conservation Status and Strategies

Due to these persistent threats, Podophyllum hexandrum is classified as an endangered species and is considered to be at high risk of extinction. Addressing this requires a combination of policy intervention and scientific conservation efforts such as in-situ conservation. There is a recognized need for government-level restrictions on the harvesting of wild plants to allow natural populations to recover. In a significant ex-situ conservation effort, 86 germplasm accessions (Himachal Pradesh-44, Jammu and Kashmir-25, Uttarakhand-14, Sikkim-2 and Arunachal Pradesh-1) were collected from various high-altitude regions of India are currently being conserved in the National Gene Bank at ICAR-NBPGR, New Delhi. A total of sixteen herbarium specimens (P. hexandrum-15 and P. peltatum-1) are also deposited in National Herbarium of Cultivated Plants at ICAR-NBPGR, New Delhi.

5.2 Threats to Wild Populations

The primary threats facing wild populations of P. hexandrum are multifaceted and interconnected:

- Over-exploitation: The plant is gathered extensively from the wild for its use in food, traditional medicine, and the commercial extraction of resin, leading to a significant decline in its natural abundance.
- Habitat Fragmentation: Increasing human activities in the Himalayan region have led to the fragmentation and degradation of its natural habitat.
- Inherent Biological Limitations: The species has several biological traits that hinder its natural recovery, including poor seed germination, extended dormancy periods, and a naturally low rate of regeneration.

5.3 Propagation Methods and Cultivation

Developing reliable propagation and cultivation techniques is crucial for reducing pressure on wild populations.

- Conventional Methods: Propagation is traditionally done using seeds or vegetative root/rhizome cuttings. However, these methods are challenging due to the low number of viable seeds and their prolonged dormancy.
- Biotechnological Alternatives: Modern techniques offer promising alternatives for mass propagation, including plant tissue culture, in vitro cell suspension cultures, and somatic embryogenesis.
- Optimal Cultivation Conditions: For successful cultivation, the plant requires well-drained, sandy loam soil with a high concentration of organic matter. It thrives in temperate and subalpine zones that provide mild summers and very cold winters.

The conservation predicament of P. hexandrum underscores the urgent need to bridge the gap between high demand and sustainable supply through dedicated and innovative scientific research.

6.0 Conclusion and Future Research Directions

P. hexandrum is an endangered, high-value medicinal plant whose immense therapeutic potential is matched only by its ecological vulnerability. While its role in traditional and modern medicine is well-established, significant gaps remain in our scientific understanding of the species. A concerted research effort is urgently required to ensure its use in both effective and sustainable manner for future generations. Future scientific inquiry must focus on bridging these knowledge gaps to develop robust conservation and cultivation strategies.

6.1 Identified Research Gaps

The following critical research gaps require immediate attention from the scientific community:

1. There is a lack of thorough investigation into the variability of bioactive compounds—both in quality and quantity—across different geographic regions and between wild versus cultivated populations.
2. Despite its importance, there is currently no established or developing agricultural variety of Podophyllum.
3. There is an insufficient understanding of the plant's chemotypes and its full diversity at the morphological, biochemical, and genetic levels.

> P. hexandrum is an endangered, high-value medicinal plant whose immense therapeutic potential is matched only by its ecological vulnerability.

6.2 Recommendations for Future Work

To address these gaps and secure the future of this valuable resource, future work should prioritize several key areas. There is an urgent need to standardize podophyllotoxin content from cultured plantlets to ensure a consistent and reliable supply for pharmaceutical production. The development and implementation of sustainable harvesting methods for wild populations are critical to prevent further depletion. Finally, comprehensive diversity studies are essential to understand the existing genetic resources within the species, which will underpin the development of effective conservation strategies and promote the sustainable utilization of this invaluable medicinal plant.

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Green Cities through Urban Farming

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In many low- and middle-income nations, rapid urbanization has emerged as a significant threat to food security (Poulsen et al., 2015). Globally, rapid urbanization has changed public health dynamics, food systems, and environmental sustainability. According to the United Nations (2018), 55% of the world's population currently resides in urban regions, and this number is expected to rise to 68% by 2050. Given this, urban agriculture is becoming more widely acknowledged as a viable approach to improve local food supply, preserve biodiversity, and fortify ecosystem services in urban areas (FAO, 2017).

As cities grow, open spaces, wetlands, and peri-urban agricultural lands are converted for non-agricultural purposes, limiting the availability of land for food production. This leads to fragmentation of green spaces and loss of biodiversity habitats, reducing ecosystem services such as pollination, soil fertility, and

micro-climate regulation. Urban agriculture has been proposed as a way to enhance a city's resilience. According to Forman (2014), urban biodiversity refers to the variety of living organisms, including plants, animals, and microorganisms, and their habitats within cities and metropolitan areas, shaped by both natural processes and human activities

Urban agriculture plays a significant role in strengthening the ecological, nutritional, social, and economic dimensions of the urban ecosystem. Urban agriculture improves green cover and biodiversity while enhancing air quality and waste recycling. It strengthens nutritional security by providing fresh, diverse food and supports healthier life by reducing dependence on external markets. Additionally, it supports livelihoods, social cohesion, and healthy living, making cities more resilient and sustainable. Urban agriculture has indeed been proposed as a means for delivering ecosystem services like benefits for mental health and cultural enrichment (Jansson,, 2013).

Moreover, urban agriculture reduces "food miles," thereby lowering greenhouse gas emissions and strengthening climate resilience (United Nations Environment Programme, 2021). Practically, urban farming enhances household income, empowers women and youth, and strengthens community cohesion. Evidence from International Food Policy Research Institute (2020) suggests that small-scale urban agricultural enterprises contribute to livelihood diversification and poverty reduction in developing countries. Additionally, urban composting initiatives convert household organic waste into valuable inputs, promoting circular economy principles (UNEP, 2021).

Urban agriculture can be promoted through rooftop and community gardens, vertical farming, hydroponics, aeroponics, aquaponics, container gardening, and controlled-environment agriculture, while smart technologies like IoT sensors, automated irrigation, climate control, data-driven crop management, and precision fertilization optimize resources and yields. These practices support sustainable food production, improve resource efficiency, and enhance urban biodiversity and resilience

According to National Family Health Survey-5 (NFHS-5, 2019–21) conducted by the Ministry of Health and Family Welfare, around 30% of urban children under five are stunted, 27% are underweight, and over 54% of women (15–49 years) are anaemic in India. In Kerala, nearly 25% of children are stunted, indicating persistent nutritional gaps despite better health indicators. These statistics highlight the need for localized food-based solutions such as urban agriculture, which can improve access to fresh, diverse, and nutrient-rich foods in cities like Thiruvananthapuram and support nutritional security and healthy living

Kerala has one of the highest urbanization rates in India, with nearly 47.7% urban population (Census 2011), and the percentage is increasing steadily. Specifically, in Thiruvananthapuram district, rapid urban expansion has led to reduced open spaces and increased dependence on external vegetable markets. Integrating urban agriculture into municipal planning and community-led extension programmes can significantly contribute to nutritional security, ecological balance, and urban resilience in the district.

The fundamental distinction between urban and rural agriculture lies in the integration of farming practices within the ecological and economic systems of the city (Anushi et al .,2024). To ensure these systems thrive, the World Bank (2012) advocates for participatory extension approaches, highlighting the critical importance of stakeholder engagement and community-based knowledge sharing in promoting sustainable initiatives. Such sustainable urban food systems are essential for achieving the United Nations' Sustainable Development Goals, specifically SDG 2 (Zero Hunger) and SDG 11 (Sustainable Cities and Communities). By fostering diverse urban ecosystems, cities can build greater ecological resilience, allowing them to better provide ecosystem services and withstand environmental pressures such as climate change impacts or extreme weather events (Gionfra et al., 2023).

Ecological planning plays a crucial role in urban design, guiding smart urbanisation that limits sprawl and minimises impacts on biodiversity while meeting development goals (Guerry et al., 2021).Urban biodiversity can be enhanced by creating green spaces, parks, and community gardens, using native plants, and promoting urban agriculture such as rooftop and vertical gardens. Conserving wetlands and waterbodies, supporting pollinators, and reducing pesticide use also help maintain species diversity. Integrating biodiversity-friendly practices into urban planning and involving communities in tree planting and habitat restoration can further strengthen ecological health in cities.

In Kerala Programs like "Haritha Keralam" have increased public awareness about sustainable food production and organic farming in cities. The state government and local self-help groups encourage families to grow vegetables such as tomato, spinach, brinjal, chili, and okra in grow bags and containers. Bengaluru is widely known for its rooftop gardening movement. Many residents grow vegetables and herbs on apartment terraces and balconies using organic methods. In Mumbai, urban agriculture projects have transformed rooftops and small unused spaces into productive farms. Hyderabad has seen rapid growth in hydroponic and vertical farming technologies. Urban farmers use nutrient-rich

> Urban agriculture plays a significant role in strengthening the ecological, nutritional, social, and economic dimensions of the urban ecosystem.

water systems to cultivate leafy vegetables without soil. These methods require less water and are suitable for densely populated urban areas. In Delhi, community gardens and urban farming projects are improving environmental sustainability and encouraging community participation. Schools, residential societies, and NGOs are actively involved in growing vegetables and promoting environmental education. These examples show how urban agriculture is helping Indian cities become greener, healthier, and more sustainable.

Urban agriculture provides many environmental and social benefits, but it also faces several important constraints. According to the Food and Agriculture Organization (FAO), limited land availability, water scarcity, insecure land tenure, and lack of policy support are major challenges affecting urban farming. The United Nations Environment Programme (UNEP) also reported that poor waste management, soil contamination, and inadequate infrastructure can reduce the sustainability of urban agriculture. In addition, the World Health Organization (WHO) warns that contaminated water and polluted soils may create health risks in urban food production. FAO further emphasizes that high investment costs and limited technical support remain significant barriers to adopting advanced urban farming systems such as hydroponics and vertical farming.

Urban agriculture has emerged as a sustainable approach to improving the quality of urban life by increasing green spaces, enhancing food security, and reducing environmental impacts. Practices such as rooftop gardening, vertical farming, and community gardens contribute to healthier ecosystems and stronger local communities.

Urban agriculture plays a significant role in strengthening the ecological, nutritional, social, and economic dimensions of the urban ecosystem.

Although challenges including limited land, water scarcity, and high implementation costs still exist, innovative technology, increasing public awareness and supportive policies can promote the successful growth of urban farming. Therefore, integrating agriculture into urban planning can help build resilient, eco-friendly cities and ensure a healthier and more sustainable future for upcoming generations.

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French Bean Rust
Diversity, Resistance and Integrated Management

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French bean (Phaseolus vulgaris L.), commonly known as snap bean or common bean, is one of the most important leguminous vegetable crops cultivated worldwide for its tender green pods and nutritious dry seeds. It is highly valued for its rich protein, carbohydrates, vitamins, minerals, and dietary fibre, making it an important component of human nutrition. In many developing countries, French bean is a major source of food security and income for small and marginal farmers. In addition to its nutritional and economic importance, the crop also improves soil fertility through biological nitrogen fixation. However, its productivity is severely affected by several fungal, bacterial, and viral diseases, among which rust caused by Uromyces appendiculatus is considered one of the most destructive foliar diseases (Stavely and Pastor-Corrales, 1989).

Symptoms of French Bean Rust

Rust disease is a serious problem in French bean cultivation across tropical, subtropical, and temperate regions. Under favourable environmental conditions, the disease can cause yield losses ranging from 25 per cent to complete crop failure, particularly when infection occurs during the early growth stages. The disease initially appears as small pale yellow or whitish chlorotic spots on both leaf surfaces. These spots gradually enlarge and develop into reddish-brown, powdery pustules called uredinia, which contain urediniospores that cause rapid secondary spread during the cropping season. These pustules may also occur on petioles, stems, and pods. As the disease progresses, infected leaves turn yellow, dry prematurely, and fall off, resulting in severe defoliation and reduced photosynthesis. At later stages, black telial pustules are formed, which help the pathogen survive adverse environmental conditions and serve as the primary inoculum for the next season (Stavely and Pastor-Corrales, 1989; Acevedo et al., 2013).

Life Cycle of the Pathogen

The causal organism, U.

Fig.1 (a) Reddish brown pustules surrounded by yellow halo on the adaxial surface, (b) Reddish brown pustules on the abaxial surface, and (c) Rust symptoms on the pod

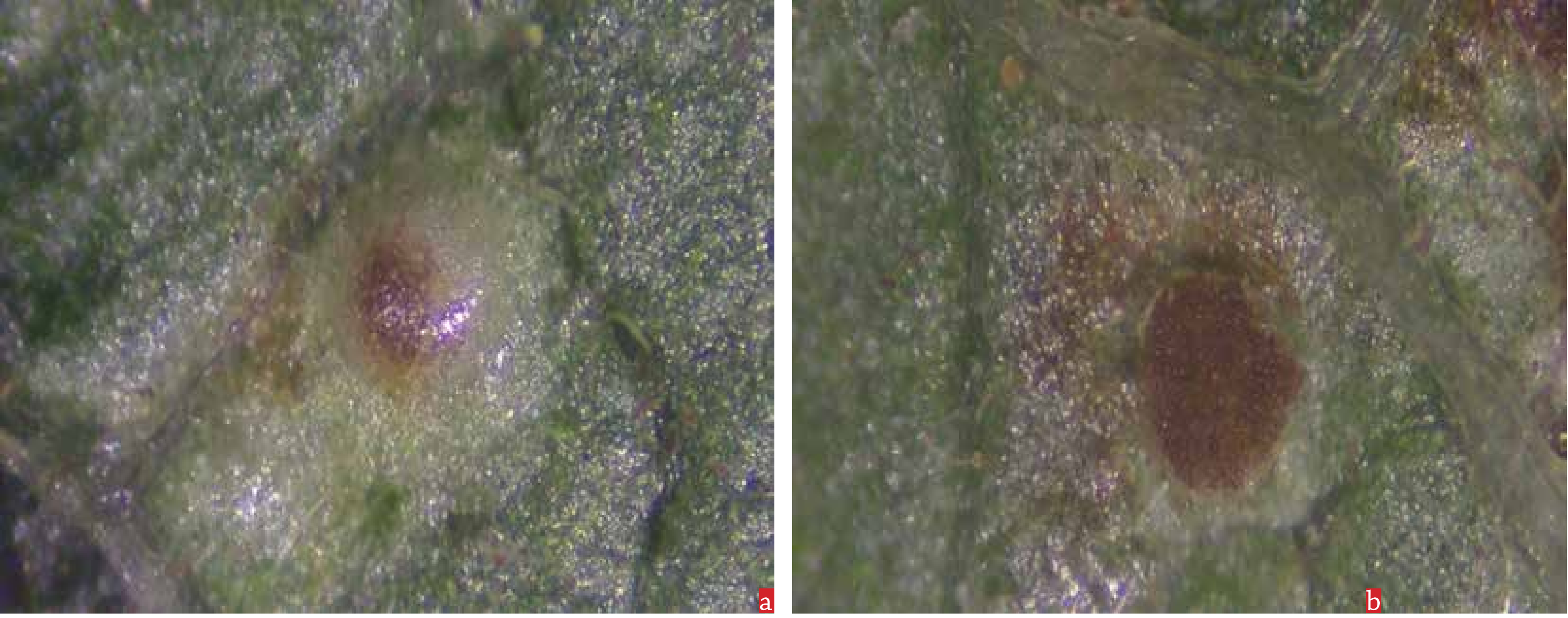

Fig.2 (a) Magnified view of developing rust pustule, and (b) Magnified view of ruptured pustule

appendiculatus, is a macrocyclic rust fungus capable of producing all five spore stages in its life cycle, namely pycniospores, aeciospores, urediniospores, teliospores, and basidiospores. Teliospores survive in infected crop debris and volunteer plants. Under suitable moisture and temperature conditions, they germinate to produce basidiospores, which infect healthy bean plants and initiate primary infection. Urediniospores produced in the uredinia are then spread by wind, rain splash, and physical contact, causing repeated secondary infections throughout the season. Since the pathogen reproduces both sexually and asexually, it exhibits remarkable genetic variability and adaptability, enabling it to overcome host resistance genes easily (Stavely and Pastor-Corrales, 1989; Araya et al., 2004).

Diversity of Uromyces appendiculatus

One of the most important characteristics of U. appendiculatus is its high pathogenic diversity. More than 100 races and over 350 pathotypes have been identified worldwide. These races differ in virulence and their ability to infect bean cultivars carrying different resistance genes. The pathogen population is broadly divided into two major groups: Andean and Middle American. Andean races are usually associated with large-seeded Andean bean types and are more host-specific, whereas Middle American races are associated with small-seeded beans and are generally more virulent with a broader host range. This variability is mainly due to mutation, sexual recombination, selection pressure from resistant cultivars, and environmental adaptation. Such high variability often leads to the breakdown of resistance in cultivars that were once considered resistant (Acevedo et al., 2013; Araya et al., 2004).

Differential Sets for Race Identification

To identify and classify races of U. appendiculatus, scientists use standard bean lines known as differential cultivars. These lines carry specific rust resistance genes called Ur genes. Initially, a seven-line differential set was developed by Harter and Zaumeyer, later expanded into a 20-line differential set in 1983, and further refined into a 12-line international differential set in 2002. Important resistance genes include Ur-3, Ur-4, Ur-5, Ur-6, Ur-7, Ur-11, Ur-12, and Ur-13. These genes are widely used in breeding programmes for developing rust-resistant varieties. Differential sets help breeders identify prevailing races in a region and select suitable resistance genes for durable resistance breeding (Miklas et al., 2006; Acevedo et al., 2013).

Resistance Mechanisms in French Bean

• Structural and Physiological Resistance

French bean plants possess several structural resistance mechanisms against rust infection. Plants with fewer stomata, smaller stomatal

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openings, and dense leaf pubescence or trichomes show better resistance because the fungus mainly enters through stomata. Leaf trichomes interfere with spore germination and germ tube movement, thereby reducing successful infection. Physiological resistance is often associated with adult plant resistance and slower disease development (Miklas et al., 2006).

- **Biochemical Resistance**

Biochemical resistance involves higher levels of phenols, peroxidase, catalase, hydrogen peroxide, and lignification. These compounds strengthen the plant cell wall and activate plant defense responses. Hydrogen peroxide acts as a signalling molecule and induces hypersensitive reactions that restrict fungal spread. Resistant cultivars usually contain higher levels of these protective compounds compared to susceptible cultivars (Miklas et al., 2006).

- **Genetic Resistance**

The genetic basis of resistance is mainly controlled by dominant genes known as Ur genes (Uromyces resistance genes). At least fourteen major resistance genes have been identified in common bean. Among them, Ur-3, Ur-4, Ur-5, Ur-6, and Ur-11 are widely used in breeding programmes. However, single-gene resistance is often short-lived because the pathogen evolves rapidly and develops virulence against specific genes. Therefore, breeders focus on gene pyramiding, where two or more resistance genes are combined in a single variety. Gene combinations such as Ur-3 + Ur-11 and Ur-5 + Ur-6 provide broader and more durable resistance against multiple races of the pathogen (Miklas et al., 2006; Araya et al., 2004).

Integrated Management of French Bean Rust

Integrated disease management is the most effective strategy for controlling French bean rust.

- **Use of Resistant Varieties**

Growing resistant varieties is the most economical and environmentally safe method. Farmers should adopt region-specific resistant cultivars with broad adaptability and durable resistance (Bhandari et al., 2023).

- **Field Sanitation**

Removal and destruction of

infected crop residues and volunteer plants help reduce primary inoculum since infected debris serves as a major source of teliospores (Stavely and Pastor-Corrales, 1989).

- **Crop Rotation**

Crop rotation with non-host crops such as maize, sorghum, and millets for two to three years helps break the disease cycle and reduces pathogen carryover (Bhandari et al., 2023).

- **Proper Plant Spacing**

Adequate spacing improves air circulation and reduces humidity around the crop canopy, thereby reducing disease development (Bhandari et al., 2023).

- **Balanced Fertilization**

Excess nitrogen increases susceptibility, while balanced nutrition with adequate potassium improves plant strength and disease resistance (Bhandari et al., 2023).

- **Fungicidal Management**

Fungicides such as mancozeb, chlorothalonil, propiconazole, hexaconazole, and tebuconazole are effective when sprayed at the early stage of disease appearance. Repeated sprays at 10-15 day intervals, depending on disease severity, provide good control (Bhandari et al., 2023).

- **Disease Monitoring**

Regular monitoring of disease incidence and race surveillance helps breeders and extension workers recommend suitable resistant varieties and timely control measures (Acevedo et al., 2013).

> Modern breeding approaches such as marker-assisted selection (MAS), molecular mapping, and genomic studies are accelerating the development of rust-resistant cultivars.

Future Prospects

Modern breeding approaches such as marker-assisted selection (MAS), molecular mapping, and genomic studies are accelerating the development of rust-resistant cultivars. DNA markers linked to Ur genes help breeders quickly identify resistant plants without waiting for field infection. Combining race-specific resistance with partial resistance, adult plant resistance, and slow-rusting mechanisms offers the best long-term strategy for sustainable rust management. Exploration of wild relatives and non-host resistance sources may also provide new genes for future breeding programmes (Miklas et al., 2006).

Conclusion

French bean rust caused by Uromyces appendiculatus continues to be one of the most serious challenges in bean production worldwide. Its high pathogenic diversity, rapid race evolution, and ability to overcome host resistance make disease management difficult. However, a clear understanding of pathogen diversity combined with resistant varieties, cultural practices, fungicide protection, and advanced breeding strategies can effectively minimize disease losses. Sustainable management of French bean rust is essential for improving productivity, farmer income, and food security in bean-growing regions. Continued research on pathogen diversity and durable resistance breeding will remain the foundation for long-term successful control of this important disease (Stavely and Pastor-Corrales, 1989; Bhandari et al., 2023).

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Evolution and Spread of Agriculture

An Overview

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Introduction

Agriculture, the cultivation of plants and the domestication of animals, marks one of the most transformative stages in human history. Before its advent, humans survived as hunter-gatherers, depending on foraging and hunting for their food supply. The shift to farming, often referred to as the Agricultural Revolution or Neolithic Revolution, led to the establishment of permanent settlements, increased food production, and eventually the rise of complex societies and civilizations. The origins and spread of agriculture occurred independently in various parts of the world and were influenced by diverse climatic, geographical, and cultural factors. This essay examines the origin, evolution, and spread of agriculture across different regions, focusing on continent-wise development.

The Initial Development of Agriculture

Agriculture originated around 10,000 years ago, approximately 8000 BCE, at the end of the last Ice Age. As the climate warmed, plants and animals suitable for domestication became more abundant, allowing early human populations to transition from nomadic lifestyles to settled farming. Several regions around the world independently developed agricultural systems,

laying the foundation for human societies' growth and development. These early centres of agriculture included the Fertile Crescent in the Middle East, East Asia, the Americas, and the African continent. Agriculture's spread and adaptation to various climates and terrains significantly impacted the social and economic structures of the regions.

The Fertile Crescent: Cradle of Agriculture

The Fertile Crescent, stretching from modern-day Iraq through Syria, Lebanon, Israel, and into Egypt, is often called the "cradle of agriculture." Its temperate climate, fertile soil, and the presence of two major rivers, the Tigris and Euphrates, made it an ideal location for early farming. Archaeological evidence shows that by 9500 BCE, the people of this region had begun cultivating wheat, barley, lentils, and peas. Along with crop domestication, the Fertile Crescent also witnessed the domestication of animals such as sheep, goats, and cattle, which provided meat, milk, wool, and labour. The development of agriculture in the Fertile Crescent led to an increase in food production, allowing communities to grow and thrive. Permanent settlements emerged, leading to the establishment of the first cities and the rise of ancient civilizations such as Mesopotamia. The agricultural surplus created in this region enabled the development of trade networks and specialization of labour, as not all members of society needed to engage in farming. This, in turn, fostered technological innovation, the creation of written languages, and the establishment of complex social structures. The domestication of plants and animals in the Fertile Crescent had far-reaching consequences for human societies, as the practices of settled farming spread to neighbouring regions such as Europe and North Africa. This region's significance cannot be overstated, as it set the precedent for the agricultural expansion that would shape human civilization for millennia.

Africa: A Diverse Agricultural Landscape

Africa, a continent of vast ecological and climatic diversity, also saw the independent development of agriculture in various regions. Agriculture in Africa adapted to the continent's different environmental conditions, from the fertile Nile Valley in the north to the savannahs and tropical rainforests of Sub-Saharan Africa. These diverse ecosystems influenced the types of crops grown and the methods of farming employed.

North Africa and the Nile River Valley

Agriculture in North Africa is closely tied to the Nile River, which flows through Egypt and into the Mediterranean Sea. Around 5000 BCE, ancient Egyptians began cultivating wheat, barley, and flax along the fertile banks of the Nile. The river's annual flooding deposited nutrient-rich silt onto the land, creating one of the most productive agricultural areas in the ancient world. Early Egyptian farmers also developed irrigation systems that allowed them to control the river's waters and grow crops throughout the year, even in the dry desert environment. The abundance of food produced by the Nile Valley's agriculture supported the growth of one of the world's earliest civilizations: Ancient Egypt. The surplus allowed for the development of large urban centres, monumental architecture (such as the pyramids), and a complex social hierarchy. Agriculture became the backbone of the Egyptian economy, with crops like wheat and barley serving as both food and a form of currency. The domestication of animals, particularly cattle, sheep, and goats, further boosted food production and labour efficiency. In contrast, the Sahara Desert, which was once a lush, green landscape, began to dry up around 2500 BCE. Before this desiccation, the Sahara supported small-scale agriculture and animal domestication. As the desert expanded, populations were forced to migrate toward more hospitable areas, such as the Nile Valley, where agricultural practices had already been established.

Sub-Saharan Africa

In Sub-Saharan Africa, agriculture developed independently in several regions, each characterized by its specific environmental conditions. In West Africa, the Niger River Valley became an important agricultural hub. Crops such as millet, sorghum, and African rice were cultivated, and by 2000 BCE, the domestication of African rice had transformed the agricultural landscape. This innovation contributed to the growth of early civilizations in West Africa, including the Ghana and Mali empires. East Africa, particularly the Ethiopian highlands, also became an important centre of agricultural development. By 3000 BCE, farmers in this region were cultivating crops such as teff, enset (false banana), and coffee. The unique geography and climate of the Ethiopian highlands necessitated the development of terrace farming, which maximized agricultural productivity in the region's hilly terrain. The Bantu migrations, which began around 3000 BCE, played a crucial role in spreading agricultural practices across Sub-Saharan Africa. The Bantu

people, who originated in the region around present-day Cameroon, introduced iron tools and new crops as they migrated southward and eastward. This dissemination of agricultural knowledge helped to shape the development of farming in regions such as southern Africa and the Great Lakes area.

Asia: A Centre for Agricultural Innovation

Asia, home to some of the world's oldest civilizations, has a rich and diverse agricultural history. The continent's vast geography, including fertile river valleys, deserts, and mountainous regions, influenced the types of crops cultivated and the agricultural practices employed. Asia played a significant role in the early development of agriculture, with several key regions emerging as centres of innovation.

East Asia

In East Asia, agriculture developed independently from the Fertile Crescent. By 8000 BCE, early farmers in the Yellow River Valley of northern China were cultivating millet, while those in the Yangtze River Valley in southern China focused on rice cultivation. These two staple crops became the foundation of East Asian agriculture. The Yangtze River's warm, wet climate provided ideal conditions for rice, while the drier conditions of the Yellow River Valley were more suitable for millet. The domestication of animals, including pigs, chickens, and cattle, further enhanced food production in East Asia. In addition to crop cultivation, Chinese farmers developed advanced irrigation systems and terrace farming techniques to manage the region's diverse landscapes. These innovations allowed for increased agricultural productivity, supporting the growth of large populations and the emergence of early Chinese dynasties, such as the Shang and Zhou. China's agricultural success had a profound influence on neighbouring regions, including Korea and Japan. Rice cultivation, in particular, spread throughout East Asia, becoming the staple crop of these societies and forming the basis of their agricultural economies.

South Asia and the Indus Valley Civilization

Agriculture in South Asia developed in the fertile floodplains of the Indus River Valley, where the Indus Valley Civilization flourished between 3300 and 1300 BCE. Crops such as wheat, barley, peas, and cotton were cultivated in this region, and the domestication of animals like water buffalo provided labour and food resources. The Indus Valley Civilization, which included major cities like Mohenjo-Daro and Harappa, relied on an agricultural surplus to support its urban population. The introduction of rice farming around 6000 BCE in the Ganges River Valley marked a significant development in South Asia's agricultural history. Rice cultivation supported larger populations and more complex societies, contributing to the rise of powerful empires such as the Maura and Gupta. In addition to staple crops, South Asia's agricultural diversity included the cultivation of sugarcane, lentils, and various spices, making the region a hub for agricultural production.

Southeast Asia

In Southeast Asia, the cultivation of rice began around 5000 BCE, particularly in the fertile river deltas of modern-day Vietnam, Thailand, and Cambodia. The region's warm, wet climate was ideal for rice farming, and the crop quickly became the foundation of Southeast Asian agriculture. The development of irrigation systems, such as the canals and reservoirs built by the Khmer Empire, allowed farmers to grow rice year-round, even during the dry season. The surplus of rice produced by these agricultural systems supported the growth of cities and the rise of powerful states, such as the kingdom of Fun an and the Khmer Empire. The spread of rice farming throughout Southeast Asia fostered the development of trade networks, linking the region to other parts of Asia and the world.

Europe: A Gradual Agricultural Transformation

Agriculture spread to Europe from the Fertile Crescent around 6000 BCE, marking the beginning of a slow transformation in European societies. Early European farmers introduced crops such as wheat, barley, and peas, as well as the domestication of cattle, sheep, and goats. However, the development of agriculture in Europe was shaped by the continent's diverse climates and landscapes, leading to regional variations in farming practices.

Southern Europe and the Mediterranean

In Southern Europe, agriculture flourished in the Mediterranean region, where crops such as wheat, barley, olives, and grapes became staples. The Mediterranean climate, characterized by warm, dry summers and mild, wet winters, was ideal for cultivating these crops. Ancient civilizations such as the Greeks and Romans made significant contributions to agricultural practices, including the development of crop rotation and irrigation systems. The agricultural surplus produced in the Mediterranean region supported trade and the growth of ancient civilizations. Olive oil and wine, both important products of Mediterranean agriculture, became central commodities in trade networks that extended throughout the ancient world.

Northern and Western Europe

In Northern and Western Europe, agriculture developed more slowly due to the region's cooler climate and dense forests. However, by 4000 BCE, Neolithic farmers in regions such as Britain, Scandinavia, and Germany were cultivating crops like wheat, barley, and oats. The domestication of cattle and sheep also played a crucial role in the development of agriculture in these regions. The Middle Ages saw significant advancements in European agriculture, particularly with the introduction of the three-field crop rotation system. This system allowed farmers to increase productivity by planting different crops in three separate fields, leaving one field fallow each year to restore soil fertility. The use of the heavy plough, which was capable of turning the clay-rich soils of Northern Europe, further contributed to increased agricultural productivity.

The Americas: Independent Agricultural Developments

Agriculture in the Americas

developed independently of the Old World, with several regions contributing to the domestication of crops and animals. The most important centres of early agriculture in the Americas were Mesoamerica, the Andes, and the eastern United States.

Mesoamerica

In Mesoamerica, agriculture began around 7000 BCE with the domestication of maize (corn), beans, and squash. These crops, often grown together in a system known as the "Three Sisters," became the cornerstone of Mesoamerican agriculture. Maize provided the main source of carbohydrates, beans contributed protein, and squash helped retain soil moisture and prevent weeds. The development of chinampas, or floating gardens, in swampy areas allowed Mesoamerican civilizations like the Maya and Aztec to produce food efficiently. These agricultural techniques supported the rise of advanced societies and the development of urban centres such as Tenochtitlan.

South America and the Andes

In South America, agriculture developed in the Andes Mountains and the Amazon Basin. The Andean region, with its steep slopes and high altitudes, posed unique challenges for farming. However, by 5000 BCE, people in the Andean highlands had domesticated crops such as potatoes, quinoa, and maize. The Inca civilization, which emerged in the 12th century, developed terrace farming to grow crops on the steep mountain slopes. These terraces, built with stone walls, helped prevent soil erosion and created flat areas for cultivation. In the Amazon Basin, indigenous peoples practiced slash-and-burn agriculture, cultivating crops such as manioc (cassava), sweet potatoes, and peanuts. This method allowed small populations to sustain themselves in the rainforest environment, but it also significantly altered the landscape.

North America

In North America, agriculture developed later than in Mesoamerica and South America. Indigenous peoples in the eastern United States, such as the Iroquois, cultivated maize, beans, and squash, using the "Three Sisters" system to maximize yields. In the arid Southwest, the Ancestral Puebloans (Anasazi) developed irrigation techniques to grow maize, beans, and cotton in the desert. The arrival of European settlers in the 16th century brought significant changes to the agricultural landscape of North America. European crops such as wheat, barley, and oats, along with livestock like cattle and horses, were introduced to the continent, transforming indigenous agricultural practices.

Oceania: Agriculture in Remote Island Nations

The development of agriculture in Oceania, which includes Australia, New Zealand, and the Pacific Islands, was shaped by the region's unique geography and isolation from other parts of the world.

Australia

Indigenous Australians did not practice large-scale agriculture as seen in other parts of the world. Instead, they engaged in land management practices known as "fire-stick farming." This involved the use of controlled burns to clear land and encourage the growth of certain plants. Small-scale cultivation of native plants, such as yams and bush potatoes, also took place in certain regions.

The Pacific Islands

In the Pacific Islands, agriculture developed around crops that could thrive in the tropical climate, such as taro, yams, and breadfruit. The Polynesians, who migrated across the Pacific Ocean, brought these crops with them as they settled on islands such as Hawaii, Samoa, and New Zealand. The cultivation of taro, in particular, played a central role in the diets of Pacific Island societies. Advanced agricultural systems, such as terraced taro fields and irrigation canals, were developed on islands like Fiji and Hawaii. These systems allowed for the efficient production of food, supporting large populations and the growth of complex societies in the Pacific region.

Conclusion

The development of agriculture was a transformative event that shaped the course of human history. From the fertile valleys of the Nile and Tigris-Euphrates rivers to the mountains of the Andes and the islands of the Pacific, agriculture took root in diverse environments and played a central role in the growth of civilizations. Each continent contributed uniquely to the global development of agriculture, reflecting the diverse cultural, environmental, and technological factors that influenced its evolution. As agriculture continues to evolve in the modern world, understanding its origins and development is crucial for addressing the challenges of food security, sustainability, and environmental stewardship. The lessons learned from early agricultural societies can guide future innovations in food production, helping to ensure that humanity can meet the needs of a growing global population while preserving the planet for future generations. ■

Financial Planning and Financial Literacy through Agriculture

A Sustainable Approach

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Introduction

Agriculture remains the backbone of India's economy, providing livelihood to approximately 55% of the population. The country leads the world in milk, pulses, and spice production and holds a significant position in the cultivation of wheat, rice, and cotton. Despite its importance, Indian farmers continue to struggle with financial instability due to poor financial planning, lack of financial literacy, and ineffective money management. In the context of Kerala, the agricultural sector is characterized by its dominance in rubber, pepper, and coconut cultivation. Kerala produces 78% of India's total natural rubber and has a thriving fisheries sector. However, the small landholding pattern and fluctuating agricultural incomes necessitate the adoption of multi-storey cropping systems to optimize land use and improve financial security. When coupled with financial literacy and planning, such sustainable agricultural practices can significantly enhance farmers' economic stability.

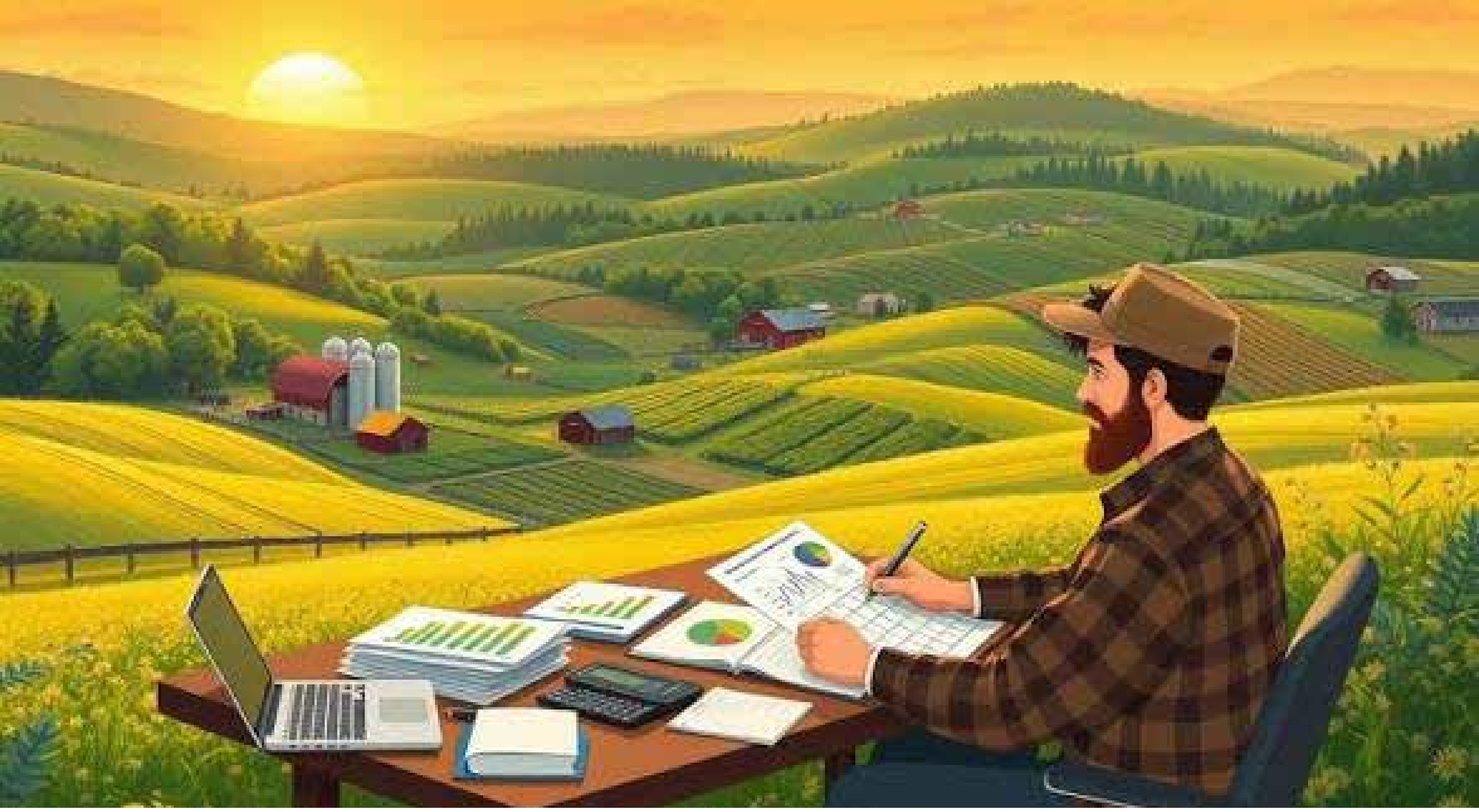
Financial Literacy: A Necessity for Farmers

Financial literacy is the ability to understand, interpret, and apply financial knowledge in areas such as budgeting, saving, investing, debt management, and wealth accumulation. It is a fundamental skill that directly impacts economic stability, particularly for farmers, who operate in an environment of income volatility and financial uncertainty. Effective financial literacy enables farmers to manage fluctuating seasonal incomes, optimize resource allocation, and make informed investment decisions that ensure long-term economic security. Additionally, it empowers them to leverage government subsidies, low-interest credit schemes, and financial assistance programs designed to support agricultural sustainability and rural development. However, the lack of financial knowledge among farmers remains a significant barrier, leading to issues such as poor credit management, over-reliance on informal lending sources with exorbitant interest rates, and vulnerability to fraudulent investment schemes. Previous research works show that financially literate farmers are more inclined to adopt innovative farming techniques, mechanization, and modern agricultural practices that enhance productivity and profitability. Furthermore, they are more likely to diversify their income sources through agribusiness ventures, value-added processing, and market-driven production strategies. Without adequate financial education, many farmers struggle with planning for contingencies such as crop failures, price fluctuations, and unforeseen expenses, often resulting in cycles of debt and economic distress. The absence of structured financial planning also limits their ability to accumulate savings, secure retirement funds, and invest in long-term assets that could stabilize their financial future. To address these challenges, financial institutions and policymakers have increasingly recognized the importance of financial education in rural areas. In Kerala, the Kerala Gramin Bank, in collaboration with the Reserve Bank of India, has taken proactive measures to bridge this knowledge gap through its Gramadeepam Financial Literacy Centres. These initiatives provide targeted financial education, helping farmers understand loan structuring, risk mitigation, savings mechanisms, and investment strategies. By equipping farmers with essential financial knowledge, these programs enable them to make well-informed decisions, improve their financial resilience, and enhance overall economic well-being. Additionally, integrating financial literacy into agricultural extension programs can further strengthen farmers' ability to participate in formal banking systems, access institutional credit at favorable terms, and build sustainable financial portfolios that contribute to the long-term growth of the agricultural sector.

Pradhanmantri Fasal Bima Yojana

Multi-Storey Cropping in Kerala: A Sustainable Agricultural Approach

Multi-storey cropping is a scientifically proven and ecologically sustainable approach that enhances farm productivity, optimizes resource utilization, and boosts profitability by making efficient use of vertical space. In Kerala, where landholding sizes are small and monocropping often leads to declining soil fertility and economic instability, coconut-based multi-storey cropping systems offer a viable solution. These integrated cropping models involve the strategic combination of crops at different canopy levels to maximize sunlight capture, improve soil health, reduce external input dependency, and ensure diversified income streams. Such systems contribute to improved microclimatic conditions by regulating temperature, humidity, and soil moisture, thereby making farms more resilient to climate change. For instance, in a typical coconut-based multi-storey cropping system, coconut palms act as the uppermost canopy layer, providing shade and organic matter through leaf litter. Black pepper, a high-value spice, can be grown as a climber on the coconut trunks, utilizing vertical space efficiently. At the mid-level, crops such as ginger and turmeric thrive under partial shade, benefiting from the organic mulch provided by the coconut trees. Simultaneously, pulses like cowpea and green gram, which are well-adapted to intercropping conditions, serve a dual purpose—enhancing soil fertility by fixing atmospheric nitrogen and generating an additional source of income. These pulses play a crucial role in



reducing the need for synthetic nitrogen fertilizers, thereby lowering production costs and improving soil sustainability over time. At the lowest layer, vegetables such as brinjal, lady's finger (okra), and leafy greens can be cultivated, taking advantage of the filtered sunlight and maintaining soil cover to prevent erosion. The inclusion of short-duration vegetable crops ensures quicker returns, bridging income gaps between major harvests. Moreover, integrating livestock such as poultry or small ruminants within the system can further enhance farm income by utilizing crop residues as feed and providing manure for organic soil enrichment. This diversified cropping approach creates a self-sustaining, biologically dynamic farming system that minimizes pest and disease outbreaks due to the presence of multiple crop species, breaking pest cycles naturally. Additionally, multi-storey cropping enhances biodiversity, supports pollinator populations, and fosters ecological balance within the farm ecosystem. By ensuring a continuous harvest throughout the year, this method reduces farmers' financial vulnerabilities, providing stability even in the face of market price fluctuations. Furthermore, it aligns with climate-smart agricultural practices by promoting carbon sequestration, reducing soil degradation, and enhancing overall farm resilience. Thus, the adoption of multi-storey cropping in Kerala not only strengthens farmers' economic security but also promotes long-term sustainability by enhancing soil fertility, improving resource efficiency, and reducing dependency on synthetic inputs. This integrative model exemplifies a holistic approach to agriculture that aligns with both environmental conservation and financial stability, making it a valuable strategy for the future of sustainable farming.

Financial Planning for Farmers: A Roadmap to Economic Security

Financial planning is essential for farmers to secure a stable and prosperous future by effectively managing income, investments, savings, and expenses. A well-structured financial plan incorporates both short-term and long-term strategies to mitigate risks and enhance economic stability. One of the most critical components of this plan is insurance, which acts as a safety net against unforeseen financial hardships. Agriculture is a high-risk profession due to its dependence on unpredictable factors like weather conditions, market fluctuations, and pest infestations. Crop insurance should be considered an integral part of farming, much like an investment cost, to protect against these uncertainties. Farmers who adopt modern technology and innovative practices are already diversifying into fields such as fisheries, and financial security will encourage more young farmers to explore these avenues. Government schemes like Pradhan Mantri Fasal Bima Yojana (PMFBY) provide financial relief in case of crop failure, ensuring that farmers do not fall into debt traps. Similarly, just as farmers insure their crops, family health insurance is equally important.

Unplanned medical expenses can be overwhelming, and without insurance, farmers might be forced to use their savings or take high-interest loans. The government's Ayushman Bharat Scheme, provides an affordable option. Financial planning should include term insurance, ideally 20 times the annual income, to ensure that families remain financially stable in the event of unforeseen circumstances. Farmers should aim for financial independence, allowing them to manage their agricultural activities without relying on external aid. Proper retirement planning ensures they can continue to sustain themselves even after they stop active farming. By investing in Systematic Investment Plans (SIPs) in mutual funds, farmers can generate a steady income, ensuring long-term wealth accumulation. Additionally, maintaining liquidity through fixed deposits and bonds provides quick access to cash during emergencies, reducing the impact of seasonal income fluctuations. Loans play a vital role in agricultural development, but poor loan management can lead to financial distress. Farmers should keep their total loan burden within five times their annual income to maintain long-term repayment feasibility. Furthermore, establishing an emergency fund equivalent to at least six months of household expenses can provide stability and reduce dependency on high-interest loans during crises. To attract new-generation farmers, agriculture needs to be treated as a business rather than just a livelihood. Those who use modern technology are seeing better profitability, and integrated farming systems, such as combining crop production with fish farming, are proving to be more sustainable. Government-backed programs like ARYA (Attracting and Retaining Youth in Agriculture) encourage young entrepreneurs to venture into farming by offering financial and technical support. Understanding the time value of money is crucial for long-term financial success. Money wisely invested grows faster than money left idle, emphasizing the need for early savings and strategic financial planning. Farmers who begin investing early benefit from compounding, which significantly amplifies financial gains over time. Financial literacy also plays a crucial role in achieving global goals like poverty reduction, food security, and economic growth. By equipping farmers with financial knowledge, they can make informed decisions, increase productivity, and contribute to the rural economy's overall development. A farmer's financial security is not just about earning income from crops but also about ensuring sustainability through insurance, investments, and financial discipline. By incorporating financial planning strategies such as crop and health insurance, systematic investments, emergency funds, and modern farming techniques, farmers can achieve economic resilience and long-term prosperity. The transformation of farming into a structured, technology-driven business model will not only empower farmers but also attract the younger generation to agriculture, ensuring a more stable and sustainable agricultural future.

Conclusion

Ensuring financial stability for farmers requires a holistic approach that integrates financial literacy, risk management, and sustainable agricultural practices. By adopting structured financial planning, including insurance, savings, and investment strategies, farmers can safeguard their livelihoods against uncertainties. Multi-storey cropping and technology-driven farming models offer viable solutions to enhance productivity and profitability, particularly in regions like Kerala. Encouraging young farmers to view agriculture as a business, supported by government initiatives, will foster long-term sustainability. A financially secure farming community will not only strengthen rural economies but also contribute to national food security and economic resilience in the years to come. ■

Better Seeds, Same Fertilizer?

Why Genetic Gains Need Nutrient Gains

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Genetic improvement in agriculture is continuous. Higher-yielding and stress-tolerant germplasm is steadily entering cultivation across crops, from heat-tolerant maize to pest-resistant cotton hybrids. Some innovations are aimed directly at increasing crops' fertilizer use efficiency. For instance, biological nitrification inhibition (BNI) in wheat, maize and other crops works by releasing root compounds that slow the conversion of ammonium to nitrate, preserving soil ammonium and making the plant more nitrogen-use efficient. Genetic gains of this kind, however, presuppose a corresponding shift in nutrient management, and that shift is rarely communicated to farmers. Research and extension institutions often fail to disseminate information on the altered nutrient regime that an improved variety requires. The result is a persistent disconnect. Several field studies show that adopters of improved crop varieties frequently apply fertilizer in much the same manner as non-adopters.

This continuous genetic improvement makes the lag in nutrient management all the more consequential, because the chemistry of fertilization in India is already badly out of balance. Optimizing chemical fertilizer use is therefore a parallel and equally urgent task. Across many states, application skews heavily toward nitrogen while phosphorus and potassium remain neglected. The Economic Survey 2025–26 documented the scale of the distortion: against an agronomic benchmark of roughly 4:2:1, the national nitrogen-phosphorus-potassium ratio, which stood at 4:3.2:1 in 2009–10, had deteriorated to approximately 10.9:4.1:1 by 2023–24, a divergence the Survey attributes overwhelmingly to excessive nitrogen application, primarily through heavily subsidized urea.

This imbalance is now compounded by external pressures on supply and market price. India meets a substantial share of its nutrient demand through imports, and that dependence is acute for the very nutrients farmers already under-apply. The country imports the majority of its DAP and the entirety of its potash, much of it routed through the Strait of Hormuz. The effective closure of the strait following the outbreak of the Iran conflict in early 2026 placed roughly one-third of global seaborne fertilizer trade at risk; through April, world urea prices approximately doubled, and DAP prices rose by about 35 percent. For Indian farmers, the implication is higher input costs and tighter availability precisely when balanced fertilization is most needed.

Such adverse conditions strengthen the case for technologies that raise nutrient-use efficiency and reduce dependence on imported inputs, and several already exist: decision-support tools for site-specific nutrient management, soil-test-based recommendations, nano-fertilizers, and efficiency-enhancing genetic traits of the kind described above. The pertinent question is not whether such technologies are available. Many are. The question is whether they reach the field and change the farmer's habit.

The two cases that follow illustrate this gap from opposite directions. Each concerns an improved crop technology whose value depends on a corresponding change in nutrient management, and both show what happens when the genetics advances, but the practice does not. The first considers a trait designed to make nitrogen use more efficient; the second, a trait designed to enrich the grain. Together they make a single point: genetic improvement and nutrient management are complementary, and neither delivers its full return alone.

Case 1. BNI Wheat: Breeding the Plant to Keep Its Own Nitrogen

Most discussion of improved seed focuses on what the plant yields. BNI shifts attention to what the soil loses, and the loss is large. Plants take up only about half of applied nitrogen fertilizer; the remainder is lost to the environment. Wheat is a particularly inefficient case. It is one of the world's largest crop consumers of nitrogen fertilizer and a relatively nitrogen-inefficient cereal.

The loss begins with soil microbes, which convert ammonium into nitrate. Nitrate moves easily: it leaches into groundwater or escapes as nitrous oxide, a greenhouse gas roughly 300 times as potent as carbon dioxide over a century. BNI-enabled plants curb this by releasing root compounds that slow the conversion, holding nitrogen in the more stable ammonium form and keeping it available to the crop for longer.

Modern wheat largely lost this capacity over decades of yield-focused breeding. Researchers have reintroduced it by transferring a chromosome segment from Leymus racemosus, a wild relative, into elite cultivars. The resulting lines released roughly double the BNI activity from their roots, suppressed nitrifying bacteria, retained more soil ammonium, and produced higher biomass and yield with no loss of grain quality. The trait, in short, works as intended without an agronomic penalty.

The implications scale quickly. Growing BNI wheat could cut nitrogen fertilizer use by 15 to 20 percent, depending on regional conditions, without sacrificing yield or quality. Applied across the world's vast wheat area, a reduction of that order would save millions of tonnes of nitrogen each year, lower input costs for farmers, and sharply reduce nitrous-oxide emissions, a meaningful figure given that agriculture contributes around 10 to 12 percent of global greenhouse-gas emissions and some 80 percent of nitrous oxide. The benefit is a genuine win on three fronts at once: farm economics, soil and water quality, and climate. The trait is now the focus of a major international effort, the CIMMYT–Novo Nordisk Foundation initiative, to verify its on-farm potential and move it toward farmers' fields.

This reframes the goal of crop improvement. For decades, breeders selected varieties that responded to heavier inputs. BNI wheat instead improves how efficiently nitrogen is held and used within the soil–plant system. It points toward a future in which varieties are designed not only to produce more, but to waste less, and the saving comes not from a purchased additive but from the plant itself.

Case 2. High-Zinc Wheat: A Rich Seed in a Poor Bed

A high-performance engine reaches its potential with the right fuel. The engineering is already sound; the gain comes from pairing it well.

Over two decades, Indian scientists have achieved a real breakthrough: high-zinc wheat varieties such as Zinc Shakti, bred to address zinc deficiency, a public-health problem linked to poor immunity, stunted growth, and adverse pregnancy outcomes. These varieties carry substantially more grain zinc than conventional wheat, and adoption across the Indo-Gangetic Plains is rising. The technology works. The opportunity now is to let it work fully, by pairing the improved seed with the nutrient practice that matches it.

Genetic and agronomic biofortification are complementary, not competing. Breeding raises the plant's baseline capacity to load zinc into the grain; zinc fertilization supplies the soil reservoir that capacity draws on. The two together reach further than either alone. This matters because much of India's wheat grows on calcareous, high-pH soils where zinc availability is naturally limited. On such soils, a well-timed zinc application, particularly a foliar spray at flowering or grain-filling, reliably raises grain zinc and its bioavailability, and often yield as well. The biofortified variety converts that input more efficiently than a conventional one, so the same practice yields a larger return.

Realizing this fully is mainly a matter of completing the package. Improved seed already moves through established distribution and promotion channels; extending the same reach to nutrient guidance would let each adopting farmer capture the variety's full benefit. The precedent is encouraging: high-yielding varieties delivered their promise once paired with irrigation, and the same logic applies here.

And the benefit is double. Zinc is not only a nutritional gain. Balanced fertilization that includes zinc also lifts yield, grain quality, and protein. The farmer is not choosing between nutrition and profitability; one practice advances both, which is precisely why the pairing is worth promoting.

Closing the Gap: From Better Seeds to Better Systems

The distance between improved genetics and outdated fertilizer practice has consequences well beyond the individual field. When a modern variety is grown under a nutrient regime designed for older cultivars, its genetic potential is only partly expressed, and the costs are at once economic, agronomic, and environmental. The farmer invests in improved seed expecting higher returns, but inefficient nutrient management caps the gain. Imbalanced application, meanwhile, depletes soil reserves, lowers nutrient-use efficiency, and raises losses through leaching, runoff, and greenhouse-gas emissions. The farmer spends more, the soil offers less, and the environmental bill grows.

The remedy is not more fertilizer but better-directed fertilizer. Recommendations must advance alongside crop genetics and become both soil-specific and variety-specific, since blanket prescriptions written decades ago fit neither modern varieties nor today's production conditions. Routine soil testing should become ordinary practice, so that shortfalls in potassium, zinc, sulphur, and other nutrients are identified and corrected before they constrain yield. Extension systems, in turn, must stop treating seed and fertilizer as separate products. An improved variety should reach the farmer together with the nutrient guidance, micronutrient recommendations, and soil-health practices that complete it. Established frameworks already exist for this: Site-Specific Nutrient Management, Integrated Plant Nutrient Supply, and 4R Nutrient Stewardship each offer practical means to raise efficiency while limiting environmental harm. Policy and subsidy design should reinforce the same goal, rewarding balanced fertilization rather than dependence on a few heavily subsidized nutrients.

The broader lesson is straightforward. Whether the innovation is BNI wheat that conserves nitrogen or high-zinc wheat that addresses hidden hunger, its success depends on the management system around it. Seed and fertilizer are not separate technologies but complementary parts of one system. India has built remarkable strength in developing improved varieties; the task now is to let nutrient management evolve with them. Better seed opens the door to agricultural transformation. Better nutrient management is what lets the farmer walk through it. ■

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