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Mahua (*Madhuca longifolia*): Review on Processing and Biological properties

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Mahua (*Madhuca longifolia*) is an economically vital, drought-resistant tree heavily ingrained in the culture and economy of Central India, including the regions of Chhattisgarh, Odisha, and Madhya Pradesh. Scientific research focuses on the cultivation, medicinal properties, and value-added processing of both its flowers and seed oil.

Mahua Cultivation and Processing

The botanical properties, propagation, and industrial applications of Mahua:

- **Processing and Biological Properties:** The harvesting practices and value addition of Mahua flowers. It highlights that the fleshy corollas are rich in natural sugars (glucose, fructose, sucrose) and details post-harvest processing methods like drying and sugar extraction.
- **Bioactive Compounds and Pharmacology:** The bioactive compounds in Mahua. It covers the tree's ecology (thriving in 550-1500 mm rainfall and sandy soils) and its medicinal properties, including antioxidant, anti-inflammatory, and antimicrobial traits.
- **Mahua in Food Technology:** Detailing how dried and powdered Mahua flowers can be used to develop value-added food products like fortified laddoos, candies, cookies, and squashes.
- **Socio-Economic Significance:** The cultural and economic importance of the Mahua tree for tribal communities. It emphasizes the importance of sustainable harvesting and decentralized governance for community empowerment.
- **Industrial Processing Guidelines:** For entrepreneurs, the National Institute of Food Technology Entrepreneurship and Management outlines standardized processing operations for both Mahua flowers (for fermentation and sugars) and seeds (for oil extraction).

Traditional vs. Modern Processing

A shift from traditional open-air sun drying and fermentation to controlled, modernized processing:

1. **Harvesting & Drying:** Flowers are collected at dawn and typically spread out in clean areas to dry in direct sunlight for 3-4 days. Modern processing often incorporates hot air ovens at temperatures around 60° C to prevent post-harvest spoilage and maintain nutritional quality.
2. **Value Addition:** Rather than just alcoholic fermentation, modern food science utilizes dried Mahua powder as a natural sweetener and ingredient in bakery and confectionery products, minimizing the reliance on refined sugars.

- **Food Product Development (Baking, Confectionery & Laddoos)**

Food scientists focus on exploiting the high reducing-sugar content (predominantly glucose and fructose) and mineral density of Mahua flowers to create nutritious, shelf-stable, and sugar-free added foods.

Flour & Powder Processing

Before inclusion into recipes, fresh flowers undergo multi-stage drying to drop moisture levels to roughly 3.15%. They are then pulverized into a fine, hygroscopic powder. This acts as both a flavoring agent and a complete replacement for refined cane sugar.

Nutri-Cereal & Wheat Laddoos

Studies focused on vulnerable demographics (like lactating women or children with malnutrition) show that composite formulations yield highly acceptable results.

- **Standardized Formulations**: In research conducted using a Composite Rotatable Experimental Design (CRD), wheat flour and finger millet (*Ragi*) are blended with dried Mahua flower powder.
- **Nutritional Gains**: A 100g serving of optimized Mahua laddoos provides excellent caloric density (≈ 429.64 kcal). It successfully meets roughly one-third of the Recommended Dietary Allowance (RDA) for iron and protein. Combining sesame seeds (*til*) or groundnuts into the formulation significantly optimizes the amino acid profile and total fat content (≈ 13.88%).

- **Bakery Applications (Cakes, Cookies & Bread)**
  - **Sugar Replacement**: Dried Mahua powder can substitute sucrose up to **40–50%** in cookies and cakes without compromising the elastic properties of dough.
  - **Maillard Reaction**: Due to its high concentration of reducing sugars, Mahua-infused baked goods achieve a deep caramel crust faster, requiring precise oven temperatures (≈ 160–175°C) to prevent bitter over-browning.

- **Medicinal Extracts & Phytochemical Profiling**

Pharmaceutical research prioritizes the isolation of secondary metabolites from Mahua flowers, bark, and leaves using polar and non-polar solvents.

Solvents and Extraction Yields

Sequential extraction experiments show varying yields based on compound polarity:

- **Petroleum ether / Chloroform**: Low yield (≈ 1.3% - 3.85%), isolates non-polar fatty acids and sterols.
- **Methanol / Ethanol**: High yield (≈ 20.25% - 30.1%), successfully extracts bioactive polyphenols, flavonoids, and glycosides.

- **Key Bioactive Compounds Identified**

Advanced analytical profiles via UPLC-Q-TOF-MS (Ultra-Performance Liquid Chromatography-Quadrupole Time-of-Flight Mass Spectrometry) reveal an abundance of therapeutic agents in the dry flower and bark:

- **Flavonoids & Phenolics**: Highly enriched with quercetin, myricetin, and gallic acid, which drive major radical scavenging properties.
- **Saponins & Triterpenoids**: Found primarily in the bark and seeds, contributing to anti-inflammatory activity.

Validated Pharmacological Actions

- **Antimicrobial & Antibiofilm**: Recent studies confirm that methanolic extracts of dried flowers exhibit extremely low Minimum Inhibitory Concentrations (MIC) against hazardous ESKAPE pathogens, notably *Enterococcus faecalis* and *Staphylococcus aureus*. They actively inhibit bacterial biofilm formation.
- **Antioxidant Efficacy**: Standardized DPPH and ABTS assays reveal that Mahua liquid concentrate exhibits antioxidant defence superior to commercial maple syrup and comparable to high-grade raw honey.
- **Traditional Therapeutics**: Extracts are clinically screened for their traditional validation as a demulcent, analgesic, and anti-diabetic agent (mediated via alpha-glucosidase enzyme inhibition by bark polyphenols).

Comparative Overview: Food Science vs. Medical Application

Attribute	Food Product Development (Laddoos/Bakery)	Medicinal Extract Formulations
Primary Part Used	Fleshy Corollas (Flowers)	Bark, Leaves, and Dried Flowers
Target Components	Glucose, Fructose, Calcium, Iron, Phosphorus	Quercetin, Gallic Acid, Saponins, Tannins
Processing Goal	Elimination of moisture, sensory score retention	Maximum recovery of bioactive yield via solvents
Key Benefit	High energy density, sugar substitute, combats anaemia	Antibacterial, anti-biofilm, anti-inflammatory

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Flowering in Vegetable Crops: Mechanisms, Regulation and Agronomic Implications

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Abstract

Flowering represents one of the most critical developmental transitions in the life cycle of vegetable crops, marking the shift from vegetative to reproductive growth. This transition is governed by a complex interplay of environmental signals (photoperiod, temperature, light intensity and water availability), physiological mediators (phytohormones) and an intricate genetic regulatory network involving circadian clock genes and floral pathway integrators. Understanding these mechanisms is pivotal for crop improvement, manipulation of flowering time and adaptation to changing climatic conditions. This review synthesizes current knowledge on the environmental, physiological and genetic control of flowering in vegetable crops, with particular emphasis on photoperiodism, vernalisation, phytohormone action and the molecular genetics of floral induction.

1. Introduction

Flowering is a pivotal developmental transition in the life cycle of plants, marking the onset of reproductive growth. During this phase, the plant shifts from accumulating biomass in vegetative structures such as leaves, roots and stems to differentiating vegetative meristems into floral meristems, culminating in the formation of functional floral organs. (Das et al., 2025; Tan et al., 2024).

The vegetative shoot apical meristem (SAM) undergoes transformation into a reproductive floral meristem, a process involving synchronized morphological changes. Three morphological stages are recognized: floral induction, floral initiation and floral differentiation. A combination of physiological, hormonal and genetic factors regulates these stages. (Singh et al., 2026).

In vegetable crops, timely flowering is economically critical. Premature bolting in leafy and root vegetables can render produce unmarketable, while delayed or incomplete flowering in fruiting vegetables directly reduces yield and seed production. Understanding and manipulating flowering thus underpins the entire chain of vegetable production, from variety development to precision crop management.

A complex interplay between exogenous environmental factors such as photoperiod, temperature, water availability and endogenous signals including hormones and genetic factors controls flowering. (Singh et al., 2026).

2. Developmental Stages of Flowering

2.1 Floral Induction

Floral induction represents a critical transition during which plants perceive environmental and endogenous signals such as photoperiod, temperature, hormonal balance and developmental age. Although no visible structural changes occur at this stage, significant physiological and molecular events take place, including the activation of flowering genes, redistribution of assimilates and changes in hormone concentrations that prepare the plant for flowering. (Singh et al., 2026).

2.2 Floral Initiation

Following floral induction, floral initiation begins with distinct morphological changes in the shoot apical meristem (SAM). The vegetative meristem enlarges, flattens and differentiates into a floral meristem, marking the onset of flower development. In vegetable crops such as tomato, onion, cabbage and cucurbits, successful initiation is essential for timely fruit set, seed production and yield.

2.3 Flower Bud Differentiation and Development

Floral differentiation encompasses the development and precise arrangement of floral organs, including sepals, petals, stamens and the pistil. Fruiting potential, fertility and flower structure are all determined at this stage. Hormonal gradients and floral homeotic genes control the precise sequence of morphological differentiation. Any disturbance during this phase, such as a hormonal imbalance or nutritional shortage, may lead to inadequate ovary growth, deformed flowers, or decreased pollen viability. (Singh et al., 2026).

3. Environmental Factors Affecting Flowering

Table 1. Summary of environmental, physiological and genetic factors influencing flowering in vegetable crops.

Factor	Category	Effect on Flowering
Photoperiod	Environmental	Regulates induction via florigen; Short day, Long day, or day-neutral responses
Temperature	Environmental	Low temperature (vernalization) promotes biennial crops; high temperature affects pollen viability
Light Intensity	Environmental	Adequate intensity promotes flower initiation and fruit set
Water Availability	Environmental	Drought can trigger premature bolting; excess delays flowering
Gibberellins	Physiological/Hormonal	Promote floral initiation, stem elongation and FT gene expression
Cytokinins	Physiological/Hormonal	Stimulate meristem activity and flower bud formation

Factor	Category	Effect on Flowering
Auxins	Physiological/Hormonal	Regulate floral organ development and assimilate transport
Ethylene	Physiological/Hormonal	Regulates sex expression in cucurbits; modifies floral gene expression
ABA	Physiological/Hormonal	Acts as flowering inhibitor under stress; delays floral transition
FT / Florigen	Genetic	Mobile signal produced in leaves; triggers flowering at shoot apex
CO (CONSTANS)	Genetic	Photoperiod sensor; activates FT when expressed in daylight
FLC	Genetic	Represses FT; suppressed by vernalization to allow flowering

3.1 Photoperiodism

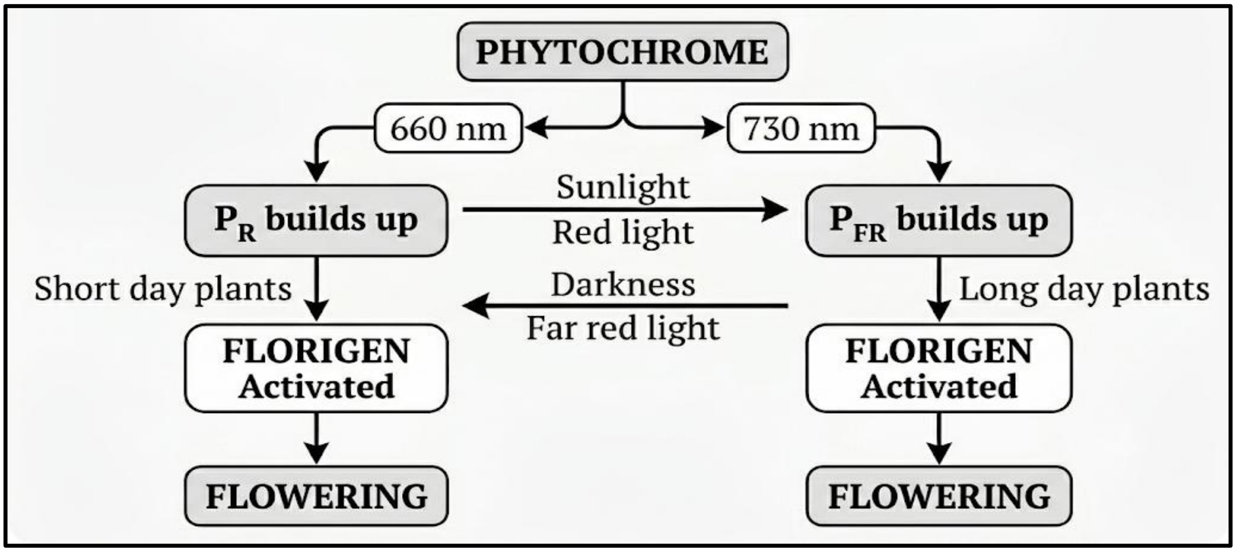
The phenomenon of photoperiodism was first discovered by American plant physiologists W.W. Garner and H.A. Allard in 1920. Photoperiodism refers to the physiological changes that occur in plants in response to the relative length of day and night. The classification of plants based on photoperiodic response is presented in Table 2. (Song et al., 2015).

Table 2. Classification of vegetable crops based on photoperiodic response.

Type	Day Length Required	Critical Factor	Examples
Short Day (SDP)	10-12 h light; 14-16 h dark	Dark period (must be continuous)	Soybean, onion, certain spinach varieties
Long Day (LDP)	14-16 h light	Light period	Radish, cabbage, sugar beet, spinach
Day Neutral (DNP)	5-24 h (any)	Not photoperiod-dependent	Tomato, brinjal, chilli, capsicum

In short day plants, the dark period is critical and must be continuous. Interruption of this dark period with even a brief exposure to red light (660-665 nm wavelength) prevents flowering. Conversely, in long day plants, the light period is critical and a brief exposure of red light during the dark period stimulates flowering. Day-neutral plants such as tomato, brinjal, chilli and capsicum can initiate flowering across a wide range of photoperiods without a specific photoperiodic stimulus. (Taiz et al., 2015).

Figure 1. Flowering in Short and Long day plants.

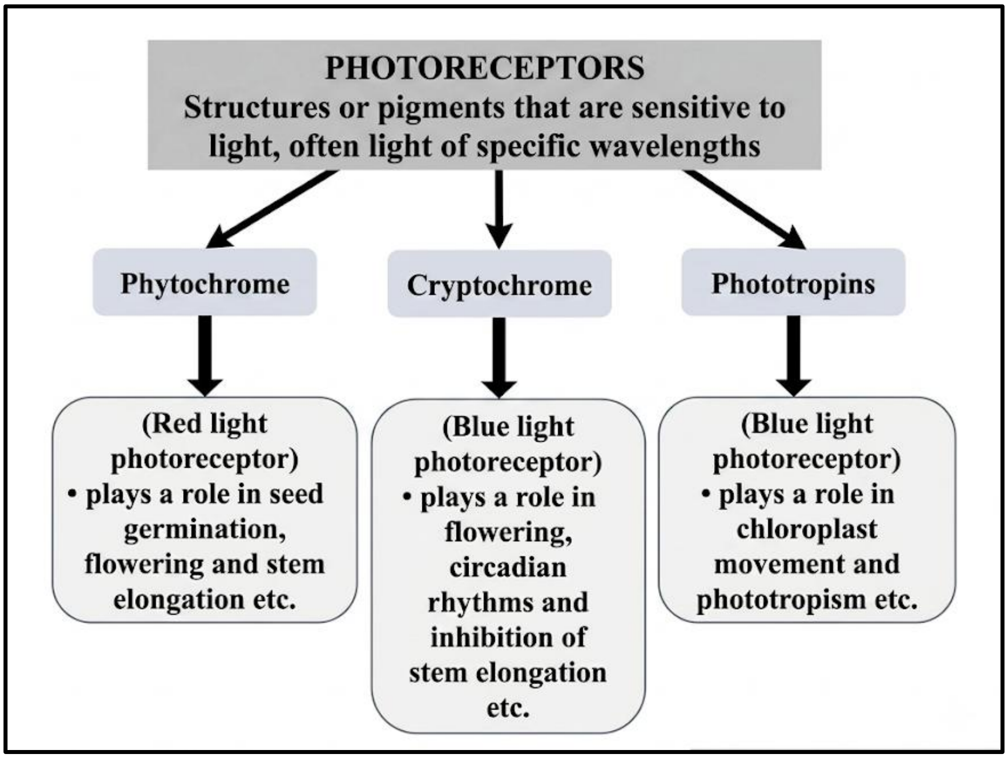


3.2 Mechanism of Photoperiodism — Florigen and Phytochrome

The perception of a suitable photoperiod by the leaves generates a floral stimulus known as florigen. Florigen is a mobile flowering signal produced in the leaves and transported through the phloem to the shoot apical meristem, where it triggers the transition from vegetative growth to reproductive growth.

Phytochrome, a biological proteinaceous pigment present in the plasma membrane, exists in two interconvertible forms: PR (inactive, absorbs red light at 660-665 nm) and PFR (active, absorbs far-red light at 730-735 nm).

Figure 2. Classification of Photoreceptors (Sarkar et al., 2024).



In short day plants, accumulation of PR in the long dark period activates florigen. In long day plants, PFR accumulated during extended light periods activates the flowering signal. (Sharma et al., 2023).

Three major classes of photoreceptors are involved in flowering regulation: (i) Phytochromes — red light photoreceptors involved in seed germination, flowering and stem elongation; (ii) Cryptochromes — blue light photoreceptors regulating flowering and circadian rhythms; and (iii) Phototropins — blue light receptors involved in chloroplast movement and phototropism (Sarkar et al., 2024).

3.3 Temperature — Vernalization and Heat Effects

Temperature acts as both a promotive signal and a stress factor depending on crop requirements and growth stage. Vernalization refers to the exposure of plants to low temperatures (0-10°C) for a specific period to induce flowering. This process is essential for biennial vegetable crops such as cabbage, celery, carrots and radishes. At the molecular level, vernalization operates via suppression of FLOWERING LOCUS C (FLC), a cold-repressive gene that normally blocks FT expression. Once temperatures rise after the cold period, FLC remains epigenetically silenced, allowing flowering to proceed. (Lee, 2025).

High temperatures can either promote flowering in warm-season vegetables or inhibit it when temperatures exceed optimum levels. Tomato flowers optimally at 21-24°C, pepper at 20-28°C, eggplant at 21-27°C, and cucurbits at 25-30°C. Above these optima, flower abortion increases, pollen viability decreases, stigma receptivity is reduced, and fruit set declines. (Chaudhary et al., 2022).

3.4 Light Intensity

Light intensity functions as both an energy source through photosynthesis and as a developmental signal regulating the vegetative-to-reproductive transition. Low light intensity delays flowering, reduces flower initiation, impairs pollen viability and increases flower and fruit drop. Optimum light intensity enhances photosynthesis, promotes early and uniform flowering and improves fruit set and yield. (Wu et al., 2025).

3.5 Water Availability

Water stress can trigger premature bolting in some vegetable crops, especially during the critical transition to flowering. Drought-induced flowering has been reported in certain pepper and tomato cultivars. Conversely, excess water during early growth can promote excessive vegetative growth at the expense of flowering. Water stress during the flowering stage often causes flower drop, where the plant sheds blossoms to conserve moisture. (Khalid et al., 2022).

4. Physiological Factors — Role of Phytohormones

Plant hormones function as key regulators of flowering by integrating environmental cues with developmental signals. Gibberellins, auxins, cytokinins, ethylene and abscisic acid work in concert to regulate the shift from vegetative to reproductive growth as well as the commencement and retention of fruits. (Singh et al., 2026; Tao et al., 2024).

- Gibberellins: Promote floral initiation and stem elongation; enhance flowering (FT) gene expression; help overcome vernalization requirements in some crops.

- Cytokinins: Promote cell division in shoot apical meristems; stimulate floral meristem activity; enhance nutrient mobilization toward developing flowers.
- Auxins: Regulate floral meristem formation and flower organ development; influence assimilate transport toward developing flower buds.
- Ethylene: Modifies floral gene expression and alters hormonal balance; regulates sex expression, particularly in cucurbits.
- Abscisic Acid (ABA): Acts as a flowering inhibitor under stress conditions; delays floral transition by suppressing growth-promoting pathways; interacts with photoperiodic and temperature pathways (Tao et al., 2024).

5. Genetic Control of Flowering

5.1 Circadian Clock and Flowering Genes

The circadian rhythm is an endogenous, self-sustained biological clock that generates approximately 24-hour cycles in physiological, biochemical and molecular processes of plants. Plants use the circadian clock together with environmental signals such as light and temperature to determine the appropriate season for flowering. (Dunlap et al., 2004).Regulation of flowering involves interaction between the circadian clock, photoreceptors and downstream flowering genes. The key genes involved are presented in Table 3.

Table 3. Key flowering genes and their functions in the circadian flowering pathway (Song et al., 2015; Venkat and Muneer, 2022).

Gene	Expression Time	Main Function	Flowering Role
CCA1	Morning	Clock regulator	Controls timing of flowering signals
LHY	Morning	Clock regulator	Synchronizes photoperiod response
TOC1	Evening	Clock feedback regulator	Maintains circadian rhythm
CO	Late afternoon/Evening	Photoperiod sensor	Activates FT gene
FT	Leaves	Florigen (mobile signal)	Induces flowering at shoot apex
FLC	Throughout	Flowering repressor	Suppressed by vernalization to allow flowering

5.2 Integration of Circadian Clock and Flowering Pathway

CONSTANS (CO) serves as the primary photoperiodic flowering regulator, acting like an alarm clock gene. The accumulation and stability of CO protein depend on the coincidence between circadian-controlled gene expression and light availability. When CO expression occurs during daylight, the protein remains stable and activates FT expression. When CO accumulates in darkness, it is degraded, preventing flowering induction. (Venkat and Muneer, 2022).

FLOWERING LOCUS T (FT) functions as the florigen, a mobile flowering signal synthesized in leaves and transported to the SAM. Once FT reaches the meristem, it interacts with the bZIP transcription factor FD and activates floral meristem identity genes including LEAFY (LFY) and APETALA1 (AP1), initiating flower development. (Venkat and Muneer, 2022; Singh et al., 2026).

FLOWERING LOCUS C (FLC) acts as a brake on the flowering pathway by repressing FT gene expression. It is suppressed epigenetically by vernalization through Polycomb Repressive Complex 2 (PRC2)-mediated H3K27me3 histone modification, enabling flowering after prolonged cold exposure. (Lee, 2025).

6. Case Studies

6.1 Case Study 1: Effect of Plant Growth Regulators on Flowering and Sex Expression in Cucumber cv. Malini (Sapkota et al., 2020)

An experiment was conducted to evaluate the effect of different PGRs on the growth, flowering behaviour, sex expression (male: female ratio), and fruit yield of the cucumber cv. Malini in a RCBD. PGRs ($AgNO_3$, ethephon, GA_3, NAA at varying concentrations) were sprayed three times starting at the 2-4 true leaf stage.

Table 4. Effect of PGR treatments on sex expression and yield of cucumber cv. Malini.

Treatment	Concentration	Effect on Flowering/Yield
GA_3	300 ppm	Highest fruit number, best yield (recommended)
GA_3	500 ppm	Most female flowers, lowest male:female ratio
Ethephon	250-500 ppm	Increased femaleness (more pistillate flowers)
$AgNO_3$	250-500 ppm	Promoted male flower formation
Control	Water spray	Baseline sex ratio and yield

Among all treatments, GA_3 at 300 ppm was the most effective, producing the greatest fruit set, highest number of fruits per plant, and maximum fruit yield. It can be recommended for commercial cucumber production.

6.2 Case Study 2: Induction of Staminate Flowers in Gynoecious Cucumber (Yadav and Singh, 2025)

A study was conducted on the gynoecious, parthenocarpic cucumber variety Pusa Seedless 6 to identify effective chemical treatments to induce staminate flowers, which are essential for hybrid seed production. Foliar sprays of GA_3, $AgNO_3$, and $Ag_2S_2O_3$ at varying concentrations were applied starting at the 2-4 true leaf stage at 7-day intervals.

Table 5. Effectiveness of chemical treatments for staminate flower induction in gynoecious cucumber.

Treatment	Concentration	Male Flowers/Plant	Recommendation
$Ag_2S_2O_3$	300 ppm	Highest	Best — recommended
$Ag_2S_2O_3$	500 ppm	High	Effective
$AgNO_3$	300-500 ppm	Moderate	Useful
GA_3	500-1000 ppm	Low-Moderate	Less effective

Treatment	Concentration	Male Flowers/Plant	Recommendation
Control	Distilled water	None	No male flowers induced

Silver thiosulphate ($Ag_2S_2O_3$) at 300 ppm was the most effective treatment. It suppressed the feminizing effect of endogenous ethylene and promoted abundant male flower formation, with earlier flowering, a longer flowering span, more staminate nodes, and the highest number of male flowers per plant.

7. Conclusion

Flowering in vegetable crops is regulated by the interaction of environmental cues and genetic pathways, with photoperiod and temperature acting as the most important external signals controlling the transition from vegetative to reproductive growth. The circadian clock integrates day length information through genes such as CCA1, LHY, TOC1, CO and FT, enabling plants to perceive seasonal changes and flower at the most favorable time for reproduction.

Photoperiodic responses differ among crop species, resulting in short-day, long-day, and day-neutral flowering behaviors that directly influence crop adaptation, productivity and geographical distribution. Phytohormones including gibberellins, cytokinins, auxins, ethylene and florigen-related signals interact with flowering genes, coordinating floral induction, flower development and reproductive success in vegetable crops.

Practical case studies demonstrate how manipulation of photoperiod, temperature, and plant growth regulators can substantially enhance flowering time, sex expression, fruit set and ultimately crop yield. Recent advances in molecular genetics and environmental physiology have improved understanding of flowering regulation, providing opportunities to develop climate-resilient, high-yielding vegetable varieties through precision breeding and crop management.

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PKM-1: A High-Yielding Drumstick (*Moringa oleifera* Lam.) Variety for Sustainable Vegetable Production in Bemetara Region of Chhattisgarh

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Abstract

Drumstick (*Moringa oleifera* Lam.) is an important perennial vegetable crop valued for its nutritional, medicinal, and economic significance. Among the improved varieties cultivated in India, PKM-1 (Periyakulam-1) is one of the most widely adopted cultivars due to its early flowering, superior pod quality, high yield potential, and adaptability to diverse agro-climatic conditions. The variety was developed by Tamil Nadu Agricultural University and has gained popularity among farmers because of its commercial viability and consumer preference. The agro-climatic conditions of Bemetara district in Chhattisgarh are highly favorable for the cultivation of PKM-1 owing to the presence of fertile soils, suitable temperature regimes, and adequate rainfall. The variety exhibits excellent adaptability under both irrigated and rainfed conditions and provides substantial economic returns through multiple harvests and continuous market demand. This article highlights the origin, morphological characteristics, flowering and fruiting behaviour, yield potential, adaptability, nutritional significance, and economic prospects of PKM-1 with special reference to the Bemetara region of Chhattisgarh.

Keywords: Drumstick, Moringa oleifera, PKM-1, Bemetara, Chhattisgarh, yield potential, vegetable crop, economic importance

Introduction

Drumstick (*Moringa oleifera* Lam.) belongs to the family Moringaceae and is one of the most important vegetable crops cultivated in tropical and subtropical regions of the world. The crop is known for its exceptional nutritional composition and medicinal properties. Almost every part of the plant, including pods, leaves, flowers, and seeds, is utilized for food, pharmaceutical, and industrial purposes (Fahey, 2005; Leone *et al.,* 2015). India is one of the leading producers and consumers of drumstick, where it forms an integral component of traditional diets and vegetable production systems. The increasing awareness regarding nutritional security and health benefits has enhanced the demand for drumstick in domestic as well as export markets (Fahey, 2005).The development of improved cultivars has significantly contributed to increasing drumstick productivity. Among them, PKM-1 has emerged as one of the most successful and commercially important varieties because of its early bearing habit, superior pod quality, and high yield potential (Rajangam *et al.,* 2001).

Origin and Development of PKM-1

PKM-1 (Periyakulam-1) was developed by Tamil Nadu Agricultural University (TNAU), Periyakulam, Tamil Nadu, through systematic selection and breeding programmes aimed at improving pod yield and quality. The variety was released for commercial cultivation due to its superior agronomic performance and wide adaptability (Rajangam *et al.,* 2001).

Morphological Characteristics

PKM-1 is a medium-sized and fast-growing variety. Plants generally attain a height of 4-6 m under normal growing conditions. The variety exhibits vigorous vegetative growth and produces numerous branches, which contribute significantly to higher pod production. The leaves are dark green, broad, and highly nutritious (Leone *et al.,* 2015). The plant possesses a strong regenerative capacity and responds well to pruning operations. Its well-developed root system enables efficient utilization of soil moisture and nutrients, contributing to drought tolerance and adaptability under varying environmental conditions (Purseglove, 1988).

Flowering and Fruiting Behaviour

One of the most important characteristics of PKM-1 is its early flowering and fruiting habit. Flowering generally commences within 90-100 days after sowing, while the first harvest can be obtained within 160-180 days. This early maturity allows farmers to obtain quicker economic returns compared with traditional drumstick cultivars (Rajangam *et al.,* 2001).The variety exhibits profuse flowering and excellent fruit-setting ability, resulting in a greater number of marketable pods per plant (Leone *et al.,* 2015).

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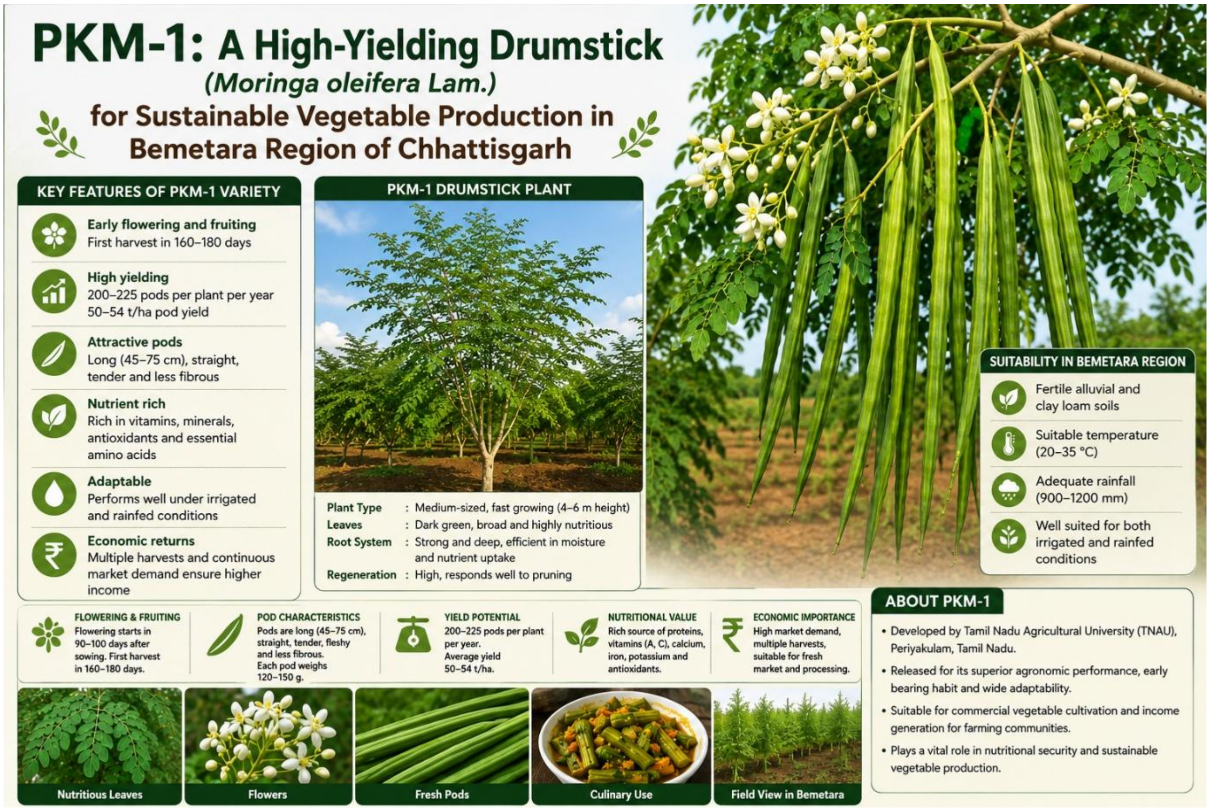

Figure 1. PKM-1 (Periyakulam-1) drumstick variety highlighting its morphological characteristics, yield potential, nutritional importance, adaptability and economic significance for sustainable vegetable production in the Bemetara region of Chhattisgarh.
(Source: Developed by the authors using AI-assisted visualization based on the information presented in this article)

Pod Characteristics

PKM-1 produces long, straight, attractive green pods with excellent consumer preference. The pods generally range from 45-75 cm in length and weigh approximately 120-150 g each. The pods are tender, fleshy, and less fibrous, making them highly suitable for fresh consumption and culinary uses (Rajangam *et al.,* 2001).

Yield Potential

PKM-1 is recognized for its outstanding yield performance. Under favourable growing conditions, a single plant may produce approximately 200-225 pods annually. Research reports indicate that the variety can achieve pod yields of 50-54 t ha^{-1}, which is considerably higher than many local cultivars (Rajangam *et al.,* 2001). Its high productivity makes PKM-1 particularly suitable for commercial vegetable cultivation and income generation among farming communities.

Nutritional Importance

Drumstick is regarded as a highly nutritious vegetable crop. The pods and leaves contain significant quantities of proteins, vitamins, minerals, antioxidants, and essential amino acids. The leaves are especially rich in vitamin A, vitamin C, calcium, iron, and potassium (Fahey, 2005; Saini *et al.,* 2016). Regular consumption of drumstick contributes to improved nutrition and health, particularly in rural populations where micronutrient deficiencies are prevalent (Fahey, 2005).

Adaptability and Suitability in Bemetara Region

Bemetara district of Chhattisgarh is characterized by a tropical sub-humid climate, fertile alluvial and clay loam soils, moderate rainfall, and favorable temperature conditions. These agro-climatic factors create an ideal environment for the cultivation of drumstick (Government of Chhattisgarh, 2024). PKM-1 has demonstrated excellent adaptability under the conditions prevailing in the Chhattisgarh plains. The variety performs well under both irrigated and rainfed situations and exhibits tolerance to short periods of moisture stress (Leone *et al.,* 2015). The fertile soils of Bemetara support vigorous vegetative growth, flowering, and pod development, thereby enabling farmers to realize the full yield potential of the variety.

Economic Importance

PKM-1 offers considerable economic benefits to farmers owing to its high productivity, multiple harvesting opportunities, and strong market demand. Compared with many seasonal vegetable crops, drumstick provides a longer productive period and relatively stable returns (Rajangam *et al.,* 2001). The increasing consumer preference for nutritious vegetables has further strengthened market demand, making drumstick cultivation a profitable enterprise. In addition, opportunities for value addition through leaf powder, dehydrated pods, and nutraceutical products are emerging, thereby increasing the economic potential of the crop (Leone *et al.,* 2015; Saini *et al.,* 2016).

Conclusion

PKM-1 is a superior drumstick variety characterised by early flowering, high yield potential, excellent pod quality, and wide adaptability. Its ability to perform well under both irrigated and rainfed conditions makes it particularly suitable for the agro-climatic conditions of Bemetara district in Chhattisgarh. The variety not only contributes to enhanced vegetable production but also supports nutritional security through its rich content of vitamins, minerals, and antioxidants. Furthermore, its high productivity, prolonged harvesting period, and strong market demand provide significant economic benefits to farmers. Therefore, the promotion and adoption of PKM-1 can play an important role in sustainable vegetable cultivation, livelihood enhancement and agricultural diversification in the region.

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Foraging Behaviour And Pollination Activities Of Stingless Bee Species

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Introduction

Stingless bees (Hymenoptera: Apidae, Meliponini) are eusocial corbiculate bees comprising more than 500 species, primarily distributed across tropical and subtropical regions. Although all stingless bee species lack the ability to sting, they retain a vestigial and non-functional sting apparatus (Michener, 2007). Stingless bees primarily depend on pollen and nectar as their main sources of nutrients, and their foraging behaviour generally involves pollen collection during the morning and nectar collection throughout the day.

Bees rely on floral resources throughout all stages of their life cycle (Michener, 2007). Nectar serves as the primary source of carbohydrates, whereas pollen provides proteins and vitamins essential for growth and development (Brodschneider & Crailsheim, 2010). In addition to pollen and nectar, stingless bees are known to collect resin and mud for constructing various nest components (Roubik, 2006; Leonhardt & Blüthgen, 2009). Resins also play a protective role within the nest by preventing predator intrusion and inhibiting the proliferation of pathogenic microorganisms (Leonhardt & Blüthgen, 2009).

Consequently, bees establish direct and essential relationships with their surrounding environment (Cole *et al*., 2017). Furthermore, stingless bees forage on a wide range of plant species and have been reported to utilize nearly 142 plant species, including vegetables, oilseed crops, spices, plantation crops, ornamental plants, forest trees, medicinal plants, and wild plants. Their pollination activities significantly contribute to crop productivity, enhancing vegetable yields by approximately 25% and increasing coconut yields by 20–40% (Devanesan *et al*., 2009).

1. Meliponiculture

Beekeeping with stingless bees is known as meliponiculture. *Tetragonula iridipennis* Smith is the most abundant stingless bee species in India and forages on diverse floral resources while exhibiting high floral fidelity (Layek & Karmakar, 2018).

Moreover, meliponiculture, the art and science of rearing stingless bees, has been practiced for centuries in many tropical and subtropical countries. Several tribal communities in the Western Ghats and northeastern regions of India possess extensive knowledge and experience in stingless beekeeping.

2. Pollination by Stingless Bees

Pollination plays a crucial role in sustainable agriculture, as the production and propagation of flowering crops depend on self-pollination or cross-pollination mechanisms. The expansion of protected cultivation systems worldwide has shifted crop production from open fields to enclosed environments. However, such conditions create physical barriers that limit access of natural pollinators to flowers.

Approximately 30% of human food production is derived from bee-pollinated crops. Both biotic and abiotic agents contribute significantly to pollination as an ecological service influencing crop productivity. About 80% of flowering plants depend on arthropods for pollination, while nearly 90% of pollination activity is supported by Apis and non-Apis bee species belonging to Hymenoptera.

Among these pollinators, *Tetragonula iridipennis* appears to be one of the most promising species. Approximately 500–600 species of Meliponini have been identified worldwide, and *Tetragonula iridipennis* Smith is the most common stingless bee species found in South India.

Similarly, another stingless bee species, *Tetragonula laeviceps*, can visit a broad range of flowering plants, including vegetable crops, fruit crops, oilseed crops, pulse crops, forage crops, weed species, ornamental plants, and flowering plants.

Additionally, stingless bees also serve as important pollinators in commercial crops belonging to families such as Leguminaceae and Cruciferae, where other honey bee species may be less effective. Arthropod pollinators improve both the qualitative and quantitative yields of chilli fruits.

3. Foraging Resources of Stingless Bees

Subsequently, a large proportion of tropical plant species, representing nearly one-fifth of local angiosperm flora, depends on pollination by stingless bees (Wilms *et al*., 1996; Corlett, 2004). Stingless bees play an important role in pollinating numerous horticultural crops by collecting nectar and pollen, thereby improving pollination efficiency and crop yields (Roubik, 1995).

Several agro-horticultural plants, including *Citrus aurantifolia, Coriandrum sativum, Lagenaria siceraria, Moringa oleifera, Citrus aurantium, Cucumis sativus,* and *Cucurbita pepo,* provide both pollen and nectar resources for stingless bees.

Furthermore, stingless bees contribute to the pollination of approximately 20 crop species and support pollination in an additional 60 crop species (Waykar and Baviskar, 2015). Likewise, they provide effective pollination services under protected cultivation systems for crops such as strawberry, eggplant, sweet pepper, tomato, and cucumber (Nunes *et al*., 2013).

4. Polylectic Behaviour of Stingless Bees

Stingless bees exhibit polylectic behaviour, meaning they collect pollen from a wide variety of floral species. They are considered manageable pollinators because of their adaptability to diverse environmental conditions and nesting habitats.

Moreover, the foraging activity of *Tetragonula iridipennis* varies according to time of day, seasonal changes, weather parameters such as wind speed, humidity, and temperature, as well as bee body size (Danaradi *et al*., 2011; Layek & Karmakar, 2018).

5. Foraging Time of Stingless Bees

The stingless bee *Tetragonula iridipennis* Smith was reported to forage for pollen primarily during the morning hours until noon (8:00 a.m.–12:00 p.m.) in Tamil Nadu, India. Resin collection activity mainly occurred between 8:00 a.m. and 11:00 a.m.

Likewise, maximum foraging activity among *Apis cerana indica* Fabricius, *Apis dorsata* Fabricius, and *Trigona* species was observed between 10:00 a.m. and 11:00 a.m., whereas *Apis florea* Fabricius exhibited peak activity between 1:00 p.m. and 3:00 p.m.

Conclusion

Stingless bees play an essential role in maintaining ecosystem stability and agricultural productivity through their efficient pollination services. Their broad floral range, polylectic foraging behaviour, adaptability to diverse environmental conditions, and effectiveness in both open-field and protected cultivation systems make them valuable pollinators for numerous agricultural and horticultural crops. *Tetragonula iridipennis*, one of the most abundant stingless bee species in India, demonstrates significant potential as a managed pollinator because of its high floral fidelity and adaptability. Furthermore, the practice of meliponiculture offers opportunities for sustainable agriculture, biodiversity conservation, and enhanced crop production. Therefore, understanding the foraging behaviour, floral resource utilization, and pollination efficiency of stingless bees is important for promoting their conservation and wider application in modern agricultural systems.

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Kharif Vegetables: Growing a Profitable Monsoon Harvest

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Introduction

The Kharif season, roughly June to October, framed by the arrival and withdrawal of the south-west monsoon, is best known to most people for rice, maize, and pulses. But it is also a critical window for vegetable cultivation, one that many farmers underuse simply because it is harder to manage than the more forgiving winter (Rabi) season. Heavy rainfall, high humidity, and heat stress make Kharif vegetable growing genuinely more demanding: waterlogging, fungal disease, and insect pressure are all higher than in winter. Yet this is precisely why Kharif vegetables matter so much — they fill the market gap when Rabi vegetables are unavailable, and prices during the monsoon months are consistently higher because supply is thinner.

For a smallholder, this translates into a straightforward opportunity: growing vegetables that are naturally suited to heat and humidity — rather than fighting the season — can turn the monsoon into one of the more profitable stretches of the farming calendar, provided some basic precautions around drainage, spacing, and disease management are taken seriously.

Why Kharif Vegetables Deserve More Attention

- **Market prices are higher:** Vegetable supply typically dips during the rains, so Kharif produce often fetches better prices than the same crop grown in winter.
- **Income diversification:** Vegetables mature faster than most Kharif cereals, giving farmers an earlier and additional income stream within the same season.
- **Better land-use efficiency:** Short-duration vegetables can be fitted into crop rotations, intercropped with longer-duration Kharif crops, or grown on bunds and field margins without competing for the main crop's land.
- **Nutritional security:** Fresh vegetables during the monsoon reduce reliance on stored or transported produce, when rural supply chains are often disrupted by rain.
- **Soil health:** Legume vegetables such as cowpea contribute to nitrogen fixation, improving soil fertility for the following crop.

Major Kharif Vegetables and How to Grow Them

Okra (Bhindi)

Okra is probably the single most reliable Kharif vegetable — it tolerates heat and moderate waterlogging better than most crops and gives a continuous harvest over two to three months. Sow directly in the field at the onset of monsoon, in rows spaced 45–60 cm apart with 20–30 cm between plants. Seeds should be soaked overnight before sowing to improve germination. Picking every 2–3 days is important — pods left too long on the plant turn fibrous and unmarketable, and delayed picking also reduces the number of new flowers the plant sets.

Brinjal (Baingan)

Brinjal is usually raised as nursery-transplanted rather than direct-sown. Raise seedlings in a nursery bed or protrays for 4–5 weeks, then transplant 45–60 cm apart on raised beds or ridges once the monsoon is established — raised planting is important here, since brinjal is particularly sensitive to waterlogging at the root zone. The main pest to watch for is the fruit and shoot borer, which tunnels into stems and fruit; regular removal and destruction of infested shoots and fruit, along with pheromone traps, helps keep populations down without heavy reliance on chemical sprays.

Chilli

Chilli nursery is typically raised 4–6 weeks ahead and transplanted onto raised beds at 45 x 45 cm or 60 x 45 cm spacing, again to protect against waterlogging. Good drainage is arguably the single most important factor in Kharif chilli — standing water at the root zone quickly leads to root rot and wilting. Leaf curl (transmitted by whitefly) and thrips are the main pest and disease pressures during the rains; growing a border crop of maize or sorghum around the chilli plot can help reduce whitefly movement into the field.

Cucurbits (Bottle Gourd, Ridge Gourd, Bitter Gourd, Pumpkin, Cucumber)

This entire family does well in Kharif and is usually grown on a pandal (bower/trellis system), which keeps fruit off wet ground, improves air circulation, and reduces fruit rot. Sow 2–3 seeds per pit at a spacing of roughly 2 x 1.5 to 2.5 x 2 metres depending on the crop, thinning to one healthy plant per pit after germination. Fruit fly is the most damaging pest across this entire group — bagging young fruit or using fruit-fly traps baited with methyl eugenol lures is far more effective than late-stage chemical spraying, since the damage happens while the larvae are already inside the fruit.

Cowpea (Lobia)

Cowpea is fast-growing, tolerant of moderate moisture stress, and fixes nitrogen in the soil, making it a useful rotation or intercrop. Direct-sow at 45–60 cm row spacing with 15–20 cm between plants; pods are ready for picking in as little as 45–55 days, making this one of the quickest-turnaround Kharif vegetables available.

Amaranthus (Chaulai / Leafy Greens)

Leafy vegetables such as amaranthus grow rapidly in the warm, humid Kharif conditions and can be ready for the first cutting within three to four weeks of sowing. Broadcast or line-sow thinly, since overcrowding encourages fungal leaf spot in humid weather, and harvest by cutting rather than uprooting to allow regrowth for a second and sometimes third harvest.

Table: Sowing, Spacing and Key Risk

Vegetable	Sowing Method	Spacing	Row/Plant Care	Harvest	Key Risk
Okra	Direct sow	45–60 x 20–30 cm	Soak seed overnight	50–55 days	Fruit borer, yellow vein mosaic
Brinjal	Nursery + transplant	45–60 cm	Raised beds essential	60–70 days	Shoot & fruit borer
Chilli	Nursery + transplant	45 x 45 cm	Raised beds, border crop	70–80 days	Leaf curl (whitefly), thrips
Bottle/Ridge/Bitter Gourd	Pit sowing	2–2.5 x 1.5–2 m	Grow on pandal/trellis	55–65 days	Fruit fly

Cowpea	Direct sow	45–60 x 15–20 cm	Nitrogen-fixing	45–55 days	Aphids, pod borer
Amaranthus	Broadcast/line sow	Thin sowing	Cut, don't uproot	21–28 days	Fungal leaf spot

Note: Sowing windows, spacing, and durations vary somewhat by variety and agro-climatic zone; farmers should confirm variety-specific recommendations with their local Krishi Vigyan Kendra before sowing.

Managing Water and Drainage in the Monsoon

Counterintuitively, Kharif vegetable failure is more often caused by too much water than too little. Waterlogging suffocates roots, encourages root and collar rot, and creates ideal conditions for fungal and bacterial diseases to spread. A few practices make the difference between a healthy stand and a washed-out one:

- **Raised beds or ridges:** essential for transplanted crops like brinjal and chilli, which are especially sensitive to waterlogged roots.
- **Field drainage channels:** cut around the plot boundary and between beds so excess rainwater has somewhere to go rather than pooling.
- **Avoid low-lying plots:** where possible, Kharif vegetables should go on land with natural slope or elevation relative to the rest of the field.
- **Mulching:** a light straw or organic mulch between rows reduces soil splash (which spreads soil-borne disease onto lower leaves) and moderates soil temperature.

Managing Pests and Diseases: An Integrated Approach

Kharif's warm, humid conditions favour both insect pests and fungal disease more than any other season, which makes prevention and monitoring more valuable than reactive spraying. A practical integrated pest management (IPM) approach for Kharif vegetables includes:

1. **Field sanitation:** removing and destroying infested fruit, shoots, and crop debris promptly, rather than leaving them to spread infection or shelter pests.
2. **Pheromone and fruit-fly traps:** effective, low-cost, and chemical-free monitoring and control tools for borers and fruit flies in brinjal, okra, and cucurbits.
3. **Border/trap cropping:** a few rows of maize, sorghum, or marigold around the main plot can intercept whitefly, aphids, and other pests before they reach the main crop.
4. **Timely, targeted spraying:** reserving chemical intervention for confirmed pest thresholds rather than routine calendar-based spraying, which is both costlier and more likely to harm natural predators.
5. **Resistant/tolerant varieties:** wherever available, choosing varieties bred for tolerance to yellow vein mosaic (okra), leaf curl (chilli), or fruit borer (brinjal) meaningfully reduces the disease and pest burden before the season even begins.

Post-Harvest Handling

Vegetables harvested during the rains spoil faster than those harvested in cooler, drier weather, simply because ambient humidity accelerates microbial growth. Harvesting in the cooler early-morning hours, avoiding harvest immediately after rainfall when produce is wet, and moving vegetables to shade quickly all help extend shelf life. For okra, cowpea, and leafy greens in particular — all of which are picked frequently — keeping harvest intervals consistent (rather than letting a picking round slip by a few days) has a direct, visible effect on both yield and quality.

Conclusion

Kharif vegetable cultivation is not simply a smaller, wetter version of Rabi vegetable growing — it calls for a different set of priorities, with drainage, disease pressure, and pest monitoring taking precedence over the concerns that dominate winter cultivation. Farmers who plan for these differences, rather than applying Rabi-season habits to a Kharif plot, stand to gain from higher monsoon-season prices, faster crop turnover, and better use of land that might otherwise sit idle between the main Kharif cereal and the Rabi vegetable season. With careful variety selection, raised-bed planting, and a proactive approach to pest and disease management, the monsoon can be turned from agriculture's most challenging season into one of its more rewarding ones.

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National Mission on Natural Farming (NMNF) for a Sustainable Agriculture

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Article ID: 27006

Introduction

Indian agriculture, at present is at its turning point. The Green Revolution, on one hand has provided food security but on the other hand it has also led to excessive dependence on chemical and synthetic input use. This has resulted in an increased cost of cultivation as well as reduction in soil fertility and environmental degradation. In order to address these challenges, the Government of India has focused on the National Mission on Natural Farming (NMNF) in its recent scale-up phase. Its aim is to promote a sustainable and eco-friendly agricultural farming system.

About the Scheme

Natural farming in India is embedded in its traditional practices. It depends on locally present resources and ecological balance. In the aftermath of Green Revolution, agriculture has shifted its focus towards intensive use of chemicals in agriculture. However, over the time, problems like soil health, human health, and environmental sustainability have focused towards renewed interest in various alternative approaches.

Initial efforts like Paramparagat Krishi Vikas Yojana (PKVY) has laid its foundation for the promotion of organic and natural farming. Due to which the National Mission on Natural Farming has been expanded into a mission-mode programme. The primary objective was to promote chemical-free farming throughout the country.

Objectives of the Mission

The mission’s aim is to promote chemical-free agriculture and encouraging natural farming practices to minimize the use of synthetic and chemical inputs. It focuses on reducing farmers’ dependency on external inputs and thereby lowering the cost of production and increasing their self-reliance. The key agenda is improving soil health and enhancing biodiversity. Which is required for long-term agricultural sustainability. The initiative also seeks to enhance farmers’ income by reducing input expenditure and increasing productivity. It supports the development of climate-resilient and sustainable farming systems. Which can help to adapt varying environmental conditions. An important function of this mission is the integration of traditional knowledge with modern agricultural practices. The motive is to ensure a balanced and holistic approach to farming.

Important Features of the Mission

The mission adopts a cluster-based approach. Wherein farmers are organized into groups to facilitate the collective adoption of natural farming practices to ensuring proper coordination and improved impact. It promotes the use of natural inputs like Jeevamrit, Beejamrit, as well as various botanical formulations. The aim is to replace chemical fertilizers and pesticides with natural ingredients. Capacity building is an important component of this mission. It focuses on training, demonstrations, and continuous field-level guidance. Its motive is to enhance farmers' skills and knowledge. Institutional support is enhanced through the active involvement of Krishi Vigyan Kendras (KVKs) and universities. To ensure credibility and market acceptance of natural farming produce, the programme promotes certification systems such as Participatory Guarantee Systems (PGS). Moreover, for effective training, dissemination of information, and advisory services, digital support is integrated through the use of Information and Communication Technology (ICT) tools.

Total Financial Outlay is ₹2,481 crore where; Central share is ₹1,584 crore and State share is ₹897 crore. Whereas, the funding pattern is 60:40 or 90:10 (Central & State share) depending on the State/UT

Eligibility Criteria under this Mission

The mission especially focuses on small and marginal farmers. Who are most likely to benefit from low-cost and sustainable agricultural practices. However, the programme is open to all the farmers. It motivates farmers to adopt natural farming methods and withdraw use of chemical-based inputs. To ensure proper understanding and effective implementation of these practices. participation in training and awareness programmes is encouraged. To promote collective learning and better outcomes farmers are also expected to adopt the approach within a cluster or group-based system. Furthermore, compliance with the use of natural inputs and adopting to sustainable farming practices are essential requirements for participation in the mission.

The initiative targeted 1 crore Farmers and land area of 7.5 lakh hectares. Total clusters formed is 15,000 (each of contiguous area covering ~50 Ha and ~125 farmers). Regarding implementation, As of Early 2026, Over 18.19 lakh farmers were enrolled. Major participation was from state of Rajasthan, Uttar Pradesh, and Andhra Pradesh. A total of 18,786 clusters were formed with 8.80

lakh hectares area under coverage. However, the area coverage has exceeded initial targets. This occurred due to the rapid scaling and state-level initiatives.

Financial Benefits and Certification

₹4,000 per acre per year output incentive for two years (up to 1 acre per farmer) to help to cover training, livestock upkeep, and bio-input preparation. It's being supported by a simplified Participatory Guarantee System (PGS) under the National Centre for Organic & Natural Farming (NCONF) in Ghaziabad.

The Implementation Strategies

The mission follows a cluster-based and farmer-centric approach. It aimed at ensuring effective implementation and wider outreach. It focuses on the development of model clusters. Which serve as demonstration sites to showcase the benefits and practical aspects of natural farming. Continuous handholding support is provided to farmers through extension services. It also enables them to adopt and sustain these practices with confidence. To maximize resource utilization and policy synergy the programme integrates with existing agricultural schemes. Emphasis is placed on farmer-to-farmer learning, encouraging knowledge sharing and peer support within communities. Additionally, to enhance the outreach, coordination, and long-term sustainability of the mission initiatives, strengthening of the local institutions is being prioritized.

Training and Infrastructure

10,000 Bio-input Resource Centres (BRCs) are targeted to supply bio-inputs like *Jeevamrit* and *Beejamrit*. Thousands of such BRCs are currently operational.Over 33,600 *Krishi Sakhis* and local trainers as **Community Resource Persons (CRPs) are** deployed for grassroots guidance. 1,100 Natural Farming Model Farms are established at Krishi Vigyan Kendras (KVKs) and Agricultural Universities.

Progress and Recent Initiatives

The mission has witnessed a significant expansion of natural farming practices across multiple states in the country. Strong initiatives have been undertaken in states such as Andhra Pradesh, Himachal Pradesh, and Gujarat. They have emerged as the key leaders in promoting natural farming. This growth has been supported by increased government funding and robust policy backing, ensuring sustained momentum. To enhance their capacity to adopt and implement natural farming techniques effectively, a large number of farmers have been trained through Krishi Vigyan

Kendras (KVKs) and extensive extension networks. To reinforce its relevance in the current environmental context, the initiative is also aligned with climate-smart agriculture and broader sustainability goals. Furthermore, for the wider dissemination of knowledge, timely access to information and advisory services, digital platforms are being increasingly utilized for farmers.

Achievements of the Mission

The mission has led to a significant reduction in the cost of cultivation. This is due to the limited use of chemical inputs, thus improving farmers' economic efficiency. It has also contributed towards improved soil health management through the enhanced use of organic matter content and increased microbial activity, vital for sustainable productivity. Farmers are experiencing more resilience towards climate variability as natural farming practices promote ecological balance as well as adaptability. Additionally, the programme has also facilitated the revival of indigenous agricultural knowledge. It has reconnected farmers with traditional and locally adapted practices. There is a growing awareness about natural farming among farmers, leading to a gradual increase in the adoption of its practices. Additionally, an evolving market demand for chemical-free produce is providing new opportunities for farmers to obtain better returns.

Adoption Challenges

The mission has faced several challenges. During the initial transition phase farmers may, experience yield fluctuations which sometimes discourage its adoption. Further, risk aversion among small and marginal farmers often restricts their willingness to shift from conventional practices to natural farming. Unawareness and restricted technical knowledge about natural farming methods also act as possible constraints to effective implementation. Additionally, the lack of regulated market linkages and premium pricing for chemical-free produce reduces the economic incentives for farmers. New or less experienced farmers often face difficulties in understanding and adopting these practices. This suggests the need for more targeted trainings and support systems.

Way Forward

It is essential to strengthen extension services and farmer training programmes. So, that farmers receive continuous guidance and practical knowledge. This would enhance the effectiveness of the mission. Further, to ensure better price realization and consumer trust in natural farming produce, it is important to developing robust market and certification systems. During this transition from conventional to natural farming, providing transitional support to farmers can help to minimize the risk and maintain their motivation. Showcasing real-life benefits and practical feasibility may also encourage wider adoption of recommended technologies. Additionally, to institutionalize these practices and ensure their long-term sustainability and scalability, integrating natural farming into education and policy frameworks will surely be helpful.

Conclusion

The National Mission on Natural Farming represents a transition in Indian agriculture. Its expansion phase emphasizes government's commitment towards farmer welfare, sustainability and environmental conservation. The mission has enormous potential to transform Indian agriculture into a low-cost, resilient and eco-friendly system. However, challenges in adoption especially among small and new farmers remains.

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