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Citrus macroptera: A Valuable Wild Citrus Fruit of Northeast India

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Introduction

Northeastern part of India is considered as one of the richest biodiversity hotspots with vegetation types ranging from tropical rain forest in the foothills to alpine meadows. The region is considered as natural home of many citrus species with wide occurrence of indigenous species like *C. macroptera, C. latipes and C. indica* (Malik *et al*., 2006). Among these, *Citrus macroptera* Montr. (Satkara) belonging to the Rutaceae family is an endangered wild species of Northeast India with a restricted distribution in the states of Meghalaya, Manipur, Mizoram and Assam. It is locally known by different names, Chambil in Garo, Heiribob in Manipuri, Hatkora in Mizo, Sohkwit in Khasi and Satkara in Assamese. This wild fruit remains underutilized and faces increasing threats due to habitat destruction and changing landuse patterns.

Characteristics

Citrus macroptera species is a perennial, evergreen fruit tree. It typically grows to a height of 5–7 m, characterized by profuse branching and a dense canopy. It is well adapted to subtropical and warm humid climates with high annual rainfall. The leaves are deep green in colour, alternately arranged, and compound, comprising 3–5 narrowly elliptic leaflets with distinct winged petioles. One of the most distinctive features of the plant is the presence of numerous long, sharp thorns. The species thrives across a wide range of soil types and climatic conditions but performs best in well drained, fertile soils. The fruits are medium-sized, highly juicy, and possess a characteristic strong sour taste. The fruits are depressed in shape, with 10-12 segments each containing 1-2 seeds. At maturity, the fruits are light yellow in colour, while the thick rind contains numerous aromatic oil glands that impart a unique fragrance and are widely used as a spice in traditional culinary preparations. Propagation is mainly carried out through seeds, although vegetative methods are also practiced. Fruits are harvested either at the green stage or after full maturity. To preserve its characteristic aroma and essential oil content, harvested fruits are protected from direct sunlight, as it can reduce their aromatic quality. The fruit is resistant to citrus greening disease and is also tolerant to psorosis and exocortis viruses.

Nutritional and Medicinal Properties

In states of NE India, the fruit is widely used as a spice in various preparations of curries and dishes, consumed as juice to aid digestion and processed into pickles after harvest. The traditional culinary uses of *C. macroptera* across different states of Northeast India are presented in Table 1. The fruit is a rich source of vitamin C, dietary fiber, essential minerals, antioxidants, and bioactive compounds such as flavonoids, phenolics, and essential oils which contribute to numerous health promoting properties. The fruit and different parts of the plant is popular among the locals for treating various ailments like fever, jaundice, alimentary disorders, stomach discomfort, loss of appetite etc. Researchers have also observed that extracts of *C.macroptera* possess antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and hepatoprotective activities. The fruits reportedly have numerous pharmaceutically important bioactive compounds which are cytotoxic, antimicrobial, antihypertensive, antipyretic, anti-diabetic and appetite stimulant potentials (Nongalleima *et al.*, 2019 and Paul *et al.*, 2015). In Manipur, *C. macroptera* fruit juice is used for stomach ailments, while the fruit peel serves as a spice and is employed in cases of dyspepsia (Singh *et al.*, 2014).


Juice (Mizoram)


Pickle (Garo Hills), Meghalaya


Dried peels (Manipur)

Table 1. Traditional culinary uses of *C.macroptera*

State	Part of fruit used	Uses	References
Mizoram and Assam	Peel	Cooked with lentil and fish in the form of decoction	De, 2016
Meghalaya (Khasi Tribes)	Peel	Pork, beef, fish and chicken is cooked with fresh or dried fruit peel	Upadhaya *et al.*, 2016
	Pulp	Sundried and pickled	
	Juice	Used as a flavoring agent to cook pork. It is believed to neutralize fat	
Meghalaya (Garo Tribes)	Peel	Fresh or dried peel is used to cook pork, beef, fish, and chicken. Delicacy of Garo with this fruit is called as "Wak Chambil Phura" it is a pork preparation with peel	Upadhaya *et al.*, 2016
	Fruit	Sundried and pickled	
Manipur	Peel	Dried and used as spice element	Nongalleima *et al.*, 2017

Decline of the species

Causes

Although the region has a rich genetic diversity of *C. macroptera*, very recently the plant population is decreasing in an alarming rate. Although many farmers are aware of its health benefits, they have shifted to cultivating other fruit crops that give more assured income and receive better government support. The plant usually starts declining with gradual decrease in vigour and yield. Declined trees not usually die but remain impoverished and unproductive. The symptoms comprised of chloratic leaves, sparse foliage, dieback of twigs and in general, a sickly appearance of the tree (Shivankar, 2000). The high rainfall and humidity prevailing in the region create a favourable environment for most of the pests and diseases, multiply and attack citrus for a longer period. Excessive soil moisture and poor drainage is also an important factor for decline. Waterlogged conditions inhibit root development, promote root rot and predispose the trees to fungal diseases like phytophthora root rot and collar rot which results in die-back of the shoots (Chaudhary *et al.*, 2016). Nutrient imbalances in both the soil and trees are indirect factors contributing to the decline. Limited knowledge of value addition and processing opportunities has also contributed to decline in cultivation of this fruit. The species is becoming endangered due to gradual decrease of farmer's interest in commercial cultivation and mostly of clearance of forest cover caused by shifting cultivation.

Management Strategies

Sustainable management of citrus decline under changing climatic conditions requires an integrated approach. Regular monitoring, early detection, and integrated pest management practices using biological, cultural, and chemical control measures are essential for minimizing pest and disease incidence. The use of certified disease free planting material, timely pruning, efficient soil and water management, and balanced nutrient application help maintain tree health and productivity. Improving soil organic matter through application of farmyard manure, vermicompost, compost and green manures further enhances soil resilience to climate stresses. Strengthening extension services through regular training and awareness programmes for citrus growers is very essential for improving good orchard management practices. Government support through subsidies, quality planting material, along with farmer's participation can further enhance the sustainability of this fruit tree. Climate adaptation practices such as mulching, rainwater harvesting etc. are also important for improving the orchards against climate variability.

Conclusion

Citrus macroptera is a unique and valuable wild citrus species of Northeast India. This citrus species is widely used as a spice in various preparations of curries and dishes, consumed as juice to aid digestion and is processed into pickles after harvest. Fresh peel of the fruit is especially used to cook with pork, beef, fish and chicken in Meghalaya. The dried peels are used as spice element in various culinary dishes of Manipur. Further juice of the fruit is consumed as a refreshing drink which aids in digestion in Mizoram. Despite of its rich biodiversity and wide range of traditional uses, the species is gradually declining due to low fertility, changing land use patterns, low commercial cultivation, pest and disease infestation, and limited awareness about its value added products. Conserving this endangered fruit requires a combination of scientific management, sustainable cultivation practices, and active participation of farming communities. Strengthening extension services, developing value added products, creating better market linkages, and providing policy support will encourage farmers to cultivate this underutilized species. Conserving *C. macroptera* is not only important for safeguarding the rich citrus genetic diversity of Northeast

India but also for preserving the traditional knowledge, food culture, and livelihood opportunities associated with this indigenous fruit.

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Water – Efficient Technologies for Sustainable Vegetable Cultivation

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Abstract

Water is the single most limiting input in vegetable production and increasing competition among agricultural, domestic and industrial users has made efficient water use an urgent priority for horticulturists and policy makers alike. Vegetables are generally shallow-rooted, fast-growing and highly sensitive to even short periods of water stress, which makes them particularly vulnerable to yield and quality losses under water scarcity, but also highly responsive to improved water management. This review synthesises current knowledge on water-saving technologies applicable to vegetable production, including drip and subsurface drip irrigation, plastic and organic mulching, deficit and regulated deficit irrigation (RDI), partial root-zone drying (PRZD), fertigation, protected cultivation, rainwater harvesting and recycled-water use, and sensor- and IoT-based precision irrigation scheduling. Evidence from field studies indicates that drip irrigation combined with mulching can reduce irrigation water use by 20–50% relative to conventional surface irrigation while maintaining or increasing marketable yield and that regulated deficit irrigation can further improve water productivity when applied during growth stages that are less sensitive to water stress. The review also discusses the practical constraints to adoption, including capital cost, technical skill requirements and site-specific calibration needs and identifies future research priorities such as integration of low-cost soil moisture sensors, remote sensing and machine-learning-based irrigation scheduling for smallholder vegetable systems. The overall conclusion is that no single technology is universally optimal; rather, the greatest water savings and economic returns are achieved when complementary technologies are combined and tailored to local soil, crop and climatic conditions.

Keywords: water-use efficiency; drip irrigation; mulching; deficit irrigation; vegetable crops; precision irrigation.

1. Introduction

Agriculture consumes nearly 70% of global freshwater resources, with irrigated vegetable production being one of the most water intensive agricultural sectors because of the high evapotranspirational demand and shallow root systems of most vegetable crops (Allen *et al.,* 1998). Increasing water scarcity caused by climate change, groundwater depletion and rising competition for water has made efficient irrigation management essential (Fereres and Soriano, 2007). Conventional surface irrigation is often inefficient, whereas modern water-saving technologies such as drip irrigation, deficit irrigation, subsurface drip irrigation, mulching, protected cultivation, soil moisture sensors, remote sensing, and automated fertigation significantly improve water-use efficiency while maintaining or enhancing crop yield and quality. Since vegetable crops are highly sensitive to water stress during critical growth stages such as flowering and fruit development (Doorenbos and Kassam, 1979), these technologies help optimize water application and reduce non-productive losses. Therefore, the adoption of water-saving technologies is vital for achieving sustainable and resource-efficient vegetable production.

2. Water-Saving Technologies in Vegetable Production

2.1 Drip and Subsurface Drip Irrigation

Drip irrigation is one of the most efficient water saving technologies in vegetable production, as it delivers water directly to the root zone, thereby reducing evaporation, runoff and deep percolation losses. In broccoli, gravity-fed drip irrigation at 80% ETc saved 21–53% of irrigation water while maintaining or increasing curd yield and improving irrigation water productivity by 46–70% compared to surface irrigation (Patra *et al.,* 2022). Likewise, subsurface drip irrigation (SSDI) further enhances water use efficiency by minimizing surface evaporation. A global meta-analysis reported that SSDI increased crop yield, irrigation water productivity and overall water productivity by 5.4%, 6.8% and 4.0%, respectively, over conventional irrigation, with the greatest benefits observed at emitter spacing below 25 cm and burial depths below 10 cm (Wang et al., 2022). Similar benefits also been reported in cotton, where alternate partial root-zone drip irrigation reduced irrigation water use by up to 30% without significantly affecting yield (Du et al., 2008).

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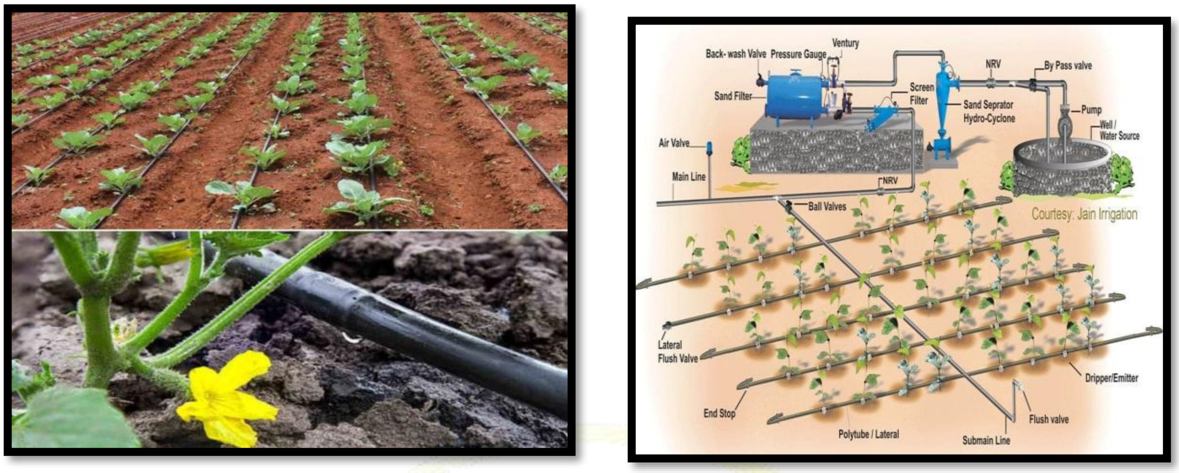

Fig. 1. Drip irrigation system in vegetable crops and layout of subsurface drip irrigation

2.2 Mulching (Plastic and Organic)

Mulching suppresses soil evaporation, moderates soil temperature and controls weeds that would otherwise compete for soil moisture. Black polyethylene mulch combined with drip irrigation has been shown to increase curd yield of broccoli by nearly 17% and crop water productivity by 15% relative to unmulched plots, with paddy-straw mulch giving a smaller but still significant benefit (Patra *et al.,* 2022). Organic mulches such as straw, crop residues or plant-based materials additionally add organic matter to the soil and are often preferred where cost or environmental concerns limit the use of plastic film. The combination of drip irrigation with plastic mulching is now regarded as one of the most reliable 'climate-smart' packages for water-scarce vegetable production, since the two technologies address complementary sources of water loss – the drip system reduces the volume applied, while the mulch reduces the volume lost to evaporation once applied (Kashyap *et al*., 2009).

Fig.2. Plastic and organic mulch in vegetables

2.3 Deficit Irrigation and Regulated Deficit Irrigation (RDI)

Deficit irrigation deliberately supplies less water than full crop evapotranspiration requirement, accepting a small, planned yield reduction in exchange for substantial water savings. Regulated deficit irrigation refines this concept by timing the imposed stress to growth stages that are least sensitive to water deficit, thereby minimising the yield penalty (Yang *et al.,* 2022). The crop yield response factor (Ky), quantifies the proportional yield loss expected per unit of relative evapotranspiration deficit and remains the standard tool for designing deficit-irrigation schedules; crops with Ky values below 1.0 tolerate water stress with a proportionally smaller yield reduction and are therefore good candidates for RDI. In broccoli, moderate deficit irrigation at 80% ETc achieved yield and profitability statistically comparable to full irrigation while using appreciably less water, whereas a more severe deficit of 60% ETc caused a measurable yield decline, illustrating the trade-off that RDI scheduling must manage (Patra *et al.,* 2022).

2.4 Partial Root-Zone Drying (PRD)

Partial root-zone drying alternates irrigation between two sides of the root system, allowing part of the roots to experience mild drying while the other part remains moist. The drying roots generate chemical signals (notably abscisic acid) that reduce stomatal conductance and transpiration without a proportional reduction in photosynthesis, so that water use efficiency improves even though total water applied is reduced (Kang and Zhang, 2004).

2.5 Fertigation and Precision Nutrient-Water Management

Fertigation, the transfer of soluble fertilisers through drip or micro-irrigation systems, allows water and nutrients to be supplied together in small, frequent doses matched to real-time crop demand. This synchronisation reduces nutrient leaching below the root zone, a common problem under conventional irrigation and fertilisation and studies in drip-irrigated tomato have shown that scheduling irrigation and nitrogen fertigation according to real-time soil moisture and crop needs markedly improves both water productivity and nitrogen-use efficiency compared with fixed calendar-based scheduling (Zotarelli et al., 2009). Because vegetable crops are typically fertilised h eavily to sustain rapid growth, fertigation is now considered an integral part of water-saving technology packages rather than a separate practice.

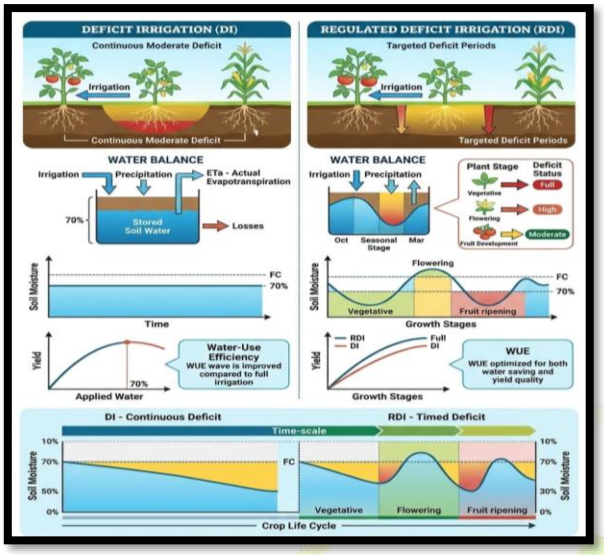

Fig. 3. Deficit Irrigation and Regulated Deficit Irrigation (RDI)

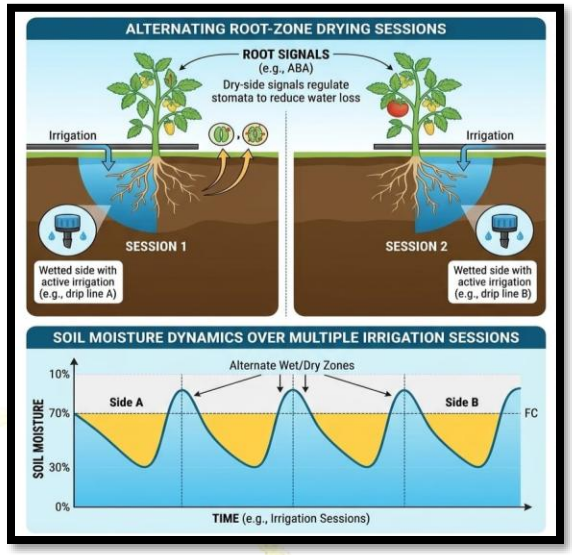

Fig. 4. Partial Root-Zone Drying

2.6 Protected Cultivation and Shade-Net Systems

Greenhouses, low tunnels and shade-net structures reduce crop water demand by moderating temperature, wind speed and vapour pressure deficit around the crop canopy, thereby lowering reference evapotranspiration relative to open-field conditions. When combined with drip irrigation, protected cultivation structures allow highly precise control over the microclimate and water supply, which is particularly valuable for high-value vegetables such as capsicum, cucumber and leafy greens grown in arid or semi-arid regions. Photo-selective shade nets additionally reduce direct solar radiation load on the crop, lowering both crop water requirement and pest pressure, making them a useful complementary water-saving tool in hot climates.

2.7 Rainwater Harvesting and Use of Treated Wastewater

In-situ and ex-situ rainwater harvesting structures, such as farm ponds, check dams and contour trenches, capture surplus monsoon or seasonal runoff for supplemental irrigation during dry spells, reducing dependence on groundwater and enabling continuity of vegetable cultivation in rain-fed areas. Similarly, treated municipal or agricultural wastewater, when used cautiously with attention to salinity and pathogen risk, provides an additional non-conventional water source; partial root-zone drying combined with recycled water has been evaluated as a way of maintaining tomato yield while easing pressure on freshwater resources in water-scarce regions, although careful monitoring of soil salinity and heavy-metal accumulation is required for sustainable long-term use.

2.8 Sensor-Based and Precision Irrigation Scheduling

Advances in low-cost soil moisture sensors, tensiometers and wireless sensor networks now allow irrigation to be triggered automatically when soil water content falls below a defined threshold, rather than on a fixed calendar basis. A real-time wireless sensor array deployed in cotton fields demonstrated that automated, sensor-triggered irrigation scheduling could reduce water applied while maintaining yield relative to conventional scheduling, a principle equally applicable to vegetable systems (Vellidis *et al.,* 2008). Complementary tools such as canopy temperature sensing, remote sensing of crop water stress index and simple plant-based indicators (leaf water potential, stomatal conductance) provide additional, non-invasive means of scheduling irrigation with high temporal precision (Jones, 2004). The integration of these sensors with Internet-of-Things (IoT) connectivity and simple decision-support software is an emerging area with strong potential for smallholder vegetable farms, since it removes much of the guesswork from irrigation timing.

3. Applications, Benefits, Constraints, Future Prospects and Conclusion

Water-saving technologies are most effective when used in combination rather than individually. Integrating drip irrigation with mulching, fertigation, and deficit irrigation has consistently resulted in greater water savings, higher water-use efficiency, and improved economic returns. In broccoli, drip irrigation at 80% ETc combined with black polyethylene mulch provided the highest benefit-cost ratio, while irrigation at 60% ETc with mulch achieved maximum water savings under severe water scarcity (Patra *et al.,* 2022). Similarly, stage-specific deficit irrigation in onion and alternate partial root-zone drip irrigation in crops such as tomato, pepper, and cotton have demonstrated considerable water savings without significant yield reduction (Doorenbos & Kassam, 1979; Du *et al*., 2008). Water conserved through efficient irrigation can also be used to expand the cultivated area, thereby increasing production without increasing total water use (Patra *et al*., 2022). Subsurface drip irrigation combined with mulching further enhances irrigation efficiency, particularly under arid conditions (Wang *et al.,* 2022). Moreover, modern tools such as soil moisture sensors, canopy temperature sensing, remote sensing, and IoT-based irrigation systems enable precise irrigation scheduling and improve water management (Jones, 2004).

The major benefits of these technologies include reduced irrigation water requirement, increased water productivity, improved crop yield and quality, reduced nutrient leaching, and lower weed and disease incidence (Fereres and Soriano, 2007). However, their adoption is often restricted by high installation costs, maintenance requirements, emitter clogging, limited technical knowledge, and inadequate crop-specific information for deficit irrigation scheduling. Plastic mulch also poses environmental concerns due to disposal issues, while sensor-based irrigation systems require improved affordability and farmer training.

Future research should focus on developing crop- and cultivar-specific water sensitivity data, affordable soil moisture sensors, remote-sensing technologies, biodegradable mulches, and integrated irrigation–fertigation systems to enhance water-use efficiency (Yang *et al.,* 2022; Jones, 2004; Vellidis *et al*., 2008). Further validation of subsurface drip irrigation and partial root-zone drying under diverse agro-climatic conditions is also essential (Wang *et al.,* 2022).

In conclusion, water-saving technologies such as drip and subsurface drip irrigation, deficit irrigation, partial root-zone drying, mulching, fertigation, and sensor-based irrigation scheduling can reduce irrigation water use by approximately 20–50% while maintaining or improving vegetable yield, quality, and profitability. Their combined application, tailored to local soil, crop, and climatic conditions, offers the most effective strategy for sustainable vegetable production under increasing water scarcity. Continued research, technological innovation, and stronger extension support are essential for promoting their large-scale adoption, particularly among smallholder farmers.

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Underutilized Vegetable Crops: Potential for Nutritional Security and Sustainable Agriculture

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Abstract

Underutilized vegetable crops are plant species that are traditionally grown in limited areas but possess high nutritional, medicinal, and economic value. Despite their adaptability to marginal environments and resilience to climate stresses, these crops have remained neglected in mainstream agriculture. In the context of increasing food and nutritional insecurity, underutilized vegetables offer a promising solution due to their rich content of vitamins, minerals, antioxidants, and bioactive compounds. Crops such as spine gourd, drumstick, amaranthus, and ivy gourd are recognized for their superior nutritional quality and ability to thrive under low-input conditions. These crops also contribute significantly to biodiversity conservation and sustainable farming systems. However, lack of awareness, limited research, poor market linkages, and absence of improved varieties hinder their large-scale adoption. Promoting underutilized vegetable crops through research, policy support, value addition, and market development can play a crucial role in improving livelihoods, ensuring nutritional security, and achieving sustainable agriculture (Padulosi *et al*., 2013; Chivenge *et al*., 2015; Mabhaudhi *et al*., 2019).

Keywords: Underutilized crops, vegetables, nutritional security, biodiversity, sustainable agriculture

Introduction

Global agriculture is dominated by a few staple crops, leading to reduced dietary diversity and increased vulnerability to food and nutritional insecurity. Underutilized vegetable crops, also referred to as neglected and underexploited species (NUS), are those that have not been widely commercialized but possess significant potential for improving nutrition, livelihoods, and environmental sustainability (Padulosi *et al*., 2013). These crops are often well adapted to local agro-climatic conditions, require fewer inputs, and are more resilient to climatic stresses, making them particularly suitable for small and marginal farmers. In India, several underutilized vegetables such as spine gourd (*Momordica dioica*), drumstick (*Moringa oleifera*), and colocasia (*Colocasia esculenta*) are traditionally cultivated and consumed but remain underexploited at the commercial level (Mabhaudhi *et al*., 2019).

Characteristics of Underutilized Vegetable Crops

Underutilized vegetable crops are characterized by their high nutritional value, adaptability to marginal and stress-prone environments, and low input requirements. They are often resistant to pests and diseases and hold significant cultural and traditional importance in local diets. These characteristics make them highly suitable for sustainable agriculture and climate-resilient farming systems. Their ability to grow under adverse conditions with minimal external inputs makes them ideal candidates for promoting eco-friendly and low-cost farming practices (Chivenge *et al*., 2015; Dawson *et al*., 2019).

Nutritional Importance

Underutilized vegetables are rich sources of essential nutrients and bioactive compounds. For instance, drumstick leaves are rich in iron, calcium, and protein, while amaranthus provides substantial amounts of vitamins A and C. Spine gourd is valued for its medicinal properties and nutritional richness. The inclusion of these crops in daily diets can significantly help in combating micronutrient deficiencies, commonly referred to as hidden hunger, and improve overall human health (Chivenge *et al*., 2015; Tontisirin *et al*., 2016). Furthermore, their high antioxidant content contributes to the prevention of chronic diseases and enhances immune function.

Role in Sustainable Agriculture

Underutilized vegetable crops play a crucial role in promoting sustainable agriculture by enhancing biodiversity, improving soil health, and reducing dependency on chemical inputs. Their adaptability to diverse environmental conditions and resilience to climate variability make them important components of climate-smart agriculture. These crops contribute to diversified cropping systems, which improve ecosystem stability and reduce production risks. Their low input requirement also supports organic farming systems and reduces the environmental footprint of agriculture (Mabhaudhi *et al*., 2019; Dawson *et al*., 2019).

Economic Potential

Underutilized vegetable crops offer significant economic opportunities for farmers, particularly through niche markets, organic production, and value-added products. With increasing consumer awareness regarding health, nutrition, and sustainable food systems, the demand for such crops is gradually rising. These crops can provide additional income sources for smallholder farmers and contribute to rural livelihood improvement. Development of value chains, processing industries, and market linkages can further enhance their commercial viability (Padulosi *et al*., 2013).

Constraints in Adoption

Despite their numerous advantages, the adoption of underutilized vegetable crops is limited due to several constraints. These include the lack of improved varieties and quality seeds, limited research and extension support, poor market infrastructure, and low consumer awareness. In addition, absence of organized supply chains and inadequate policy support further hinder their commercialization. Addressing these constraints is essential for unlocking the potential of these crops.

Strategies for Promotion

Promotion of underutilized vegetable crops requires a multi-dimensional approach involving research, policy support, and market development. Efforts should focus on the development of improved varieties, strengthening seed systems, and enhancing research on agronomic practices. Awareness programs and training for farmers and consumers are essential to increase adoption and consumption. Additionally, the development of value chains, market linkages, and inclusion of these crops in government nutrition and agricultural programs can significantly boost their cultivation and utilization (Mabhaudhi *et al*., 2019).

Conclusion

Underutilized vegetable crops hold immense potential for improving nutritional security, enhancing biodiversity, and promoting sustainable agriculture. Their resilience to climate stress and adaptability to low-input conditions make them highly suitable for future farming systems. Focused efforts in research, policy support, and market development are essential to unlock their full potential and integrate them into mainstream agriculture. Promoting these crops can contribute significantly to food and nutritional security while supporting sustainable and climate-resilient agricultural practices.

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Video-Based Extension: How Short-Form and Vernacular Video Content is Reshaping Farmer Learning

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Introduction

For decades, agricultural extension in India and much of the developing world has leaned on a familiar toolkit such as field demonstrations, printed pamphlets, radio broadcasts and the physical visit of an extension officer. Each of these channels carries a hidden assumption that the farmer receiving the message can read a leaflet, understands the language of a bulletin drafted in a state or national tongue or is fortunate enough to fall within the working radius of an already overstretched extension worker. With India's farmer-to-extension-worker ratio remaining heavily skewed and functional literacy uneven across rural belts, text-based advisories have long struggled to reach the very audience they are designed for. Over the past decade and a half, video has quietly emerged as the channel that sidesteps both constraints at once. Whether through the deliberately engineered peer-video model pioneered by Digital Green (Gandhi *et al.,* 2009) or the organic explosion of farmer-run YouTube channels and Instagram reels, moving images narrated in a farmer friendly language are proving to be a more inclusive and more trusted medium than the printed word ever was.

The Limits of Text-Based Advisory and the Turn to Video

Text-based extension material, however well researched, carries a built-in filter, it privileges the literate, the fluent and those with the leisure to sit and read. For a farmer juggling irrigation schedules, livestock and market visits, a dense advisory bulletin is rarely the first thing opened. Video collapses this filter. A two- or three-minute clip that shows, rather than tells, how to space a nursery bed or identify an early blight symptom communicates in a register that does not depend on reading ability. When that clip is also narrated in the farmer's own language and features people who look and speak like the audience, it does something a pamphlet cannot, it builds credibility through familiarity rather than authority.

The Digital Green Model: Engineering Trust Through Peer Video

Digital Green, founded in the mid-2000s, built its entire extension philosophy around this insight (Gandhi et al., 2009). Rather than filming subject-matter experts, the organisation trains local farmers to script, act in and narrate short instructional videos that are then screened to small groups by community facilitators, followed by structured discussion. The model rests on four pillars: participatory content production, a locally generated video library, human-mediated screening rather than passive broadcast and a sequenced roll-out into new communities.

The evidence base behind this approach is unusually strong for an extension intervention. An early proof-of-concept trial across sixteen villages found that Digital Green style dissemination lifted adoption of promoted practices by roughly six to seven times over a conventional training-and-visit approach, at close to a tenth of the cost per adoption. A subsequent two-year randomised trial conducted by the International Food Policy Research Institute in Ethiopia found that the video-enabled approach reached about a quarter more farmers than the standard public extension system and produced up to 44 per cent higher uptake of the practices being promoted, with adoption spilling over even to farmers who had not directly viewed a screening (Abate *et al.,* 2023). A separate randomised evaluation in Bihar, conducted with Innovations for Poverty Action (J-PAL, 2025), recorded a 50 per cent gain in adoption of system-of-rice-intensification practices alongside a 21 per cent increase in paddy output relative to the state's own rural livelihoods programme. More recent work BY Baul *et al.,* 2024, has continued to find that supplementing conventional extension with repeated video viewing among women farmers produces adoption gains of a similar order, even though the videos add no live human interaction beyond the original session. Taken together, these studies converge on a common mechanism: extension agents who use video appear to visit farms more often and follow up more diligently than those relying on lecture-style training alone and farmers consistently report greater trust in advice delivered by a recognisable peer than by an unfamiliar official.

Farmer-YouTubers and the Reels Economy: Peer Influence Without a Programme Budget

What Digital Green engineered deliberately, India's social media landscape has since produced organically. A new generation of farmer-creators now runs YouTube channels with subscriber counts that rival national broadcasters, channels built by working farmers documenting their own fields, machinery reviews and troubleshooting rather than by institutions. Channels such as Farming Leader, My Kisan Dost and Pramod's Life have each drawn subscriber bases in the millions, built entirely on the same currency that made Digital Green effective: a presenter the audience recognises as one of their own, speaking in a shared dialect about problems the viewer is actually facing. Short-form Reels and YouTube Shorts have compressed this further, turning a single sowing tip or pest-identification trick into content that spreads through WhatsApp groups and family networks as readily as a forwarded photograph (Tan, 2024).

Recent scholarship on India's evolving digital extension landscape frames this as part of a broader shift in which platforms such as WhatsApp and YouTube have become genuine sites of farmer-to-farmer knowledge exchange, with the rise of agri-influencers and peer communication accelerating the spread of new ideas even as it raises fresh concerns about misinformation and the need for stronger digital literacy and verification support (Coggins *et al.,* 2022). Unlike Digital Green's curated library, this content is unmediated: there is no facilitator guiding discussion, no participatory scripting process, and no institutional quality check before a video reaches a farmer's feed. Its reach and relatability are real, but so is its vulnerability to unverified or commercially motivated claims.

Why Vernacular, Visual Content Succeeds Where Text Advisories Fall Short

A recent scoping review of video-mediated extension studies across Africa, covering more than forty peer-reviewed evaluations, found that video content delivered in local languages and accompanied by facilitator-led discussion was consistently associated with stronger knowledge retention and higher rates of practice adoption than video viewed without such support and that group viewing further strengthened social learning and community engagement (Kimaro *et al.,* 2026). This lines up with what the Digital Green and farmer-influencer evidence shows separately: it is not video as a format that drives the effect, but the combination of vernacular narration, a relatable presenter, and, where possible, a social viewing or discussion context that text-based leaflets have never been able to replicate.

The distribution layer matters just as much as the content itself. A study examining how extension workers in Bihar circulated wheat agronomy videos found that WhatsApp accounted for the great majority of video sharing between extension workers and farmers, precisely because the platform was already deeply embedded in the daily social fabric of these communities (Sharma *et* *al.,* 2024). Video advisory, in other words, does not merely replace the printed pamphlet with a screen; it rides on pre-existing networks of trust, family groups, village circles, and peer contacts, that a mailed or posted bulletin never had access to in the first place.

Persistent Gaps and the Road Ahead

None of the above mentioned facts makes video a complete substitute for structured extension. Smartphone ownership, data affordability and digital literacy remain uneven across gender and geography and women farmers in particular continue to report lower rates of independent extension contact even where video content is locally available. The unmediated nature of influencer-driven content also means that accurate, evidence-based advice circulates alongside unverified or promotional claims, with no editorial process to separate the two. The way forward is unlikely to be a simple choice between institutional video programmes and organic social media content; the stronger evidence base points to blended models that pair vernacular, peer-presented video with human facilitation, whether from a trained community resource person or a moderated WhatsApp group, so that the trust video builds is matched with the accuracy that structured extension is meant to guarantee.

Conclusion

Whether deliberately produced by an organisation like Digital Green or independently built by a farmer with a smartphone and a YouTube channel, video-based extension succeeds for the same underlying reason: it replaces the anonymous authority of a printed advisory with the recognisable voice of a peer, delivered in a language the viewer actually speaks. As short-form and vernacular video content continues to reshape how farmers learn, the task ahead for extension planners is not to choose between the engineered and the organic model, but to borrow the credibility of both while restoring the quality safeguards that only structured facilitation can provide.

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Manipulating Plant Microbiomes for Sustainable Management of Plant Diseases

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Introduction

Plant diseases remain a major constraint to crop production and are responsible for considerable losses in agricultural systems. Conventional disease management has largely depended on resistant cultivars, chemical pesticides and cultural practices. Although these approaches remain important, repeated and intensive use of chemical pesticides can contribute to environmental contamination, disruption of non-target microorganisms and development of resistant pathogen populations. These limitations have increased interest in biological and ecological approaches that use naturally occurring interactions between plants and microorganisms for disease management. Plants are colonized by diverse microbial communities in the rhizosphere, phyllosphere and endosphere. Collectively, these microorganisms constitute the plant microbiome and influence nutrient acquisition, growth, stress tolerance and plant immunity (Trivedi *et al*., 2020). Beneficial bacteria and fungi can also restrict pathogen establishment through competition, antibiosis, parasitism and induction of plant defence responses. Consequently, manipulation of plant-associated microbial communities is increasingly being considered as a complementary approach to conventional plant disease management.

The rhizosphere is particularly important because root exudates provide carbon compounds and other metabolites that influence microbial recruitment and community assembly. Plants can select particular microorganisms from the surrounding soil, while the associated microbes can influence plant metabolism and defence. Under pathogen attack, plants may alter their exudation patterns and recruit beneficial microorganisms, a phenomenon often described as a “cry-for-help” response (Andargie *et al.,* 2023). Understanding these interactions provides a basis for developing disease-suppressive microbiomes rather than relying solely on individual microbial antagonists. Recent advances in metagenomics, metabolomics, high-throughput sequencing and microbial ecology have made it possible to examine plant-associated microbial communities at greater depth. These technologies are providing new opportunities to identify microorganisms and microbial functions associated with disease suppression and to develop strategies for deliberately modifying microbiome composition and activity (Compant *et al.,* 2025).

Plant Microbiome and Disease Suppression

Disease suppression by plant-associated microorganisms can occur through direct and indirect mechanisms. Direct suppression involves competition for nutrients and space, production of antimicrobial compounds, secretion of hydrolytic enzymes and parasitism of pathogens. Beneficial bacteria belonging to groups such as *Bacillus*, *Pseudomonas* and *Streptomyces*, together with antagonistic fungi, have been widely investigated for their ability to restrict plant pathogens. Competition for nutrients is particularly important in the rhizosphere. Beneficial microorganisms can rapidly colonize root surfaces and consume nutrients required by pathogens. Siderophore production is another important mechanism because microorganisms can bind iron and reduce its availability to competing pathogens. Some beneficial bacteria also produce antibiotics and other secondary metabolites that directly inhibit pathogen growth (Andargie *et al*., 2023).

Indirect disease suppression occurs through stimulation of plant defence. Beneficial microorganisms can activate induced systemic resistance (ISR), priming plants to respond more rapidly to pathogen invasion. This process involves complex interactions among microbial signals and plant hormones, particularly jasmonic acid and ethylene, although salicylic acid-related pathways may also contribute depending on the host–microbe interaction (Trivedi *et aal*.,2020).

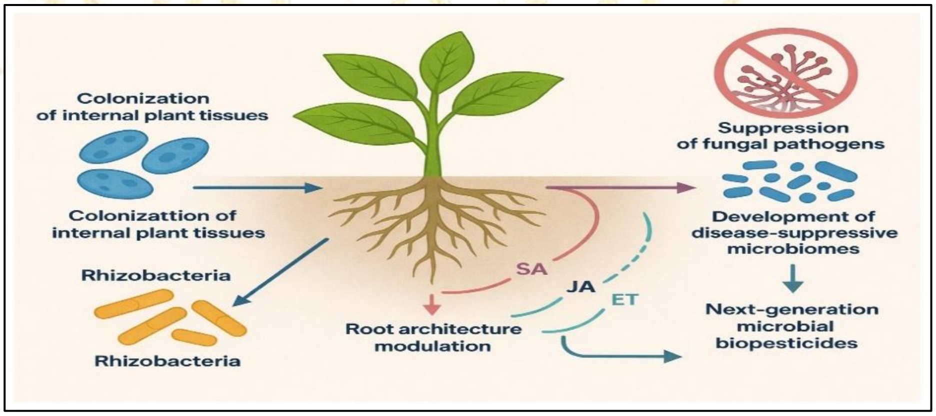

Figure:-Mechanistic role of endophytes and rhizobacteria in plant defence, microbiome assembly and suppression of fungal pathogens. Adapted from Danesh *et al.* (2026).

An important characteristic of microbiome-mediated resistance is that disease suppression does not necessarily depend on one microbial species. A diverse microbial community may provide several complementary functions, including nutrient competition, antimicrobial production, immune stimulation and ecological exclusion of pathogens. Therefore, maintaining a functionally active microbial community may be more reliable than introducing a single microbial antagonist.

Factors Affecting Microbiome Assembly and Disease Suppression

The composition of the plant microbiome is influenced by both biotic and abiotic factors. Plant genotype, developmental stage, root exudates, soil type, pH, nutrient availability, temperature, moisture and agricultural practices can all influence microbial community assembly. Because these factors interact, changing one component does not necessarily result in predictable changes in microbiome function (Andargie *et al*., 2023). Root exudates are particularly important in shaping the rhizosphere microbiome. Plants release sugars, amino acids, organic acids, phenolics and other compounds into the surrounding soil. These substances provide nutrients for microorganisms and can influence the recruitment of particular microbial groups. During pathogen infection, changes in root metabolism and exudation may favour microorganisms capable of contributing to disease suppression.

Soil properties also strongly influence microbiome-mediated disease management. Soil pH and nutrient availability can affect microbial diversity and the abundance of beneficial microorganisms. Organic amendments, compost, crop rotation, cover crops and reduced tillage can modify soil microbial communities and may increase disease suppressiveness (Chen *et al*., 2023). The concept of disease-suppressive soil provides an important example of natural microbiome-mediated disease control. In suppressive soils, pathogens may fail to establish, remain at low population densities or cause less severe disease. Suppression may result from the combined activity of many microorganisms or from specific microbial groups with strong antagonistic activity against particular pathogens (Andargie *et al*., 2023).

Strategies for Manipulating Plant Microbiomes

Manipulation of the plant microbiome can be achieved through several approaches. The simplest strategies involve modification of agricultural practices to favour beneficial microorganisms. Crop rotation, cover cropping, organic amendments and appropriate nutrient management can influence microbial community composition and improve soil health. Such approaches do not necessarily introduce new microorganisms but modify the environment in a way that favours naturally occurring beneficial populations (Chen *et al.,* 2023). A second approach involves the application of microbial inoculants. Beneficial bacteria, fungi and mycorrhizal microorganisms can be introduced to seeds, roots, soil or plant surfaces. These inoculants may improve plant growth and reduce disease through direct antagonism or stimulation of plant defence. However, their performance can vary under field conditions because introduced microorganisms must compete with established native communities and adapt to environmental conditions.

The limitations of single-strain inoculants have encouraged research into synthetic microbial communities (SynComs). SynComs consist of selected microbial strains combined to perform complementary functions. Rather than depending on one microorganism, a SynCom can potentially combine pathogen antagonism, root colonization, nutrient acquisition and immune stimulation. Recent research has shown increasing interest in rationally designed microbial communities for crop protection (Panchal *et al*., 2026). Microbiome manipulation can also involve enrichment of naturally occurring beneficial microorganisms. Plants or soils with disease-suppressive characteristics can serve as sources of beneficial microbial communities. These communities may be transferred or enriched in disease-conducive soils. Such approaches aim to restore microbial functions rather than simply adding individual antagonists.

Modern sequencing technologies provide another opportunity for microbiome manipulation. Metagenomic and metatranscriptomic analyses can identify microbial taxa and functions associated with disease suppression. Metabolomic studies can further identify compounds involved in communication among plants, beneficial microorganisms and pathogens. Integrating these datasets may help identify microbial combinations that are more stable and effective under field conditions (Compant *et al*., 2025).

Microbiome Engineering and Sustainable Disease Management

The concept of microbiome engineering extends beyond simple microbial inoculation. It involves deliberate modification of microbial communities to obtain specific functions, such as pathogen suppression or enhanced plant immunity. Recent work has proposed the use of ecological principles, microbial interaction networks and computational approaches to design more effective microbial communities (Panchal *et al*., 2026). One major advantage of microbiome-based disease management is that it can operate through several mechanisms simultaneously. A disease-suppressive community may restrict pathogen growth through competition while also stimulating plant defence. Such multifunctionality may reduce the likelihood that pathogens overcome the control mechanism compared with approaches based on a single mode of action.

However, successful microbiome engineering remains challenging. Introduced microorganisms may fail to establish because of competition with native microbes or unsuitable environmental conditions. Microbial communities can also change with crop genotype, soil characteristics and climate. Compant *et al*. (2025) emphasized that inconsistent performance under field conditions remains one of the major limitations to the wider application of plant microbiome technologies. Therefore, future microbiome-based disease management should focus on function rather than microbial composition alone. The presence of a particular bacterial or fungal taxon does not necessarily guarantee disease suppression. More attention should be given to microbial genes, metabolites, ecological interactions and functional traits responsible for disease reduction.

Future Perspectives

Future research should combine microbiome science with plant pathology, molecular biology, soil science and bioinformatics. High-throughput sequencing can identify microorganisms associated with healthy and diseased plants, while metabolomics and transcriptomics can help determine how these microorganisms influence plant defence and pathogen behaviour. Synthetic microbial communities represent an important direction because they allow researchers to select microorganisms with complementary functions. Recent research has reported the potential of SynComs for crop protection in several crops, including tomato, rice, wheat and maize (Panchal *et al*., 2026). Nevertheless, their stability and effectiveness under different field environments need further evaluation.

Climate variability should also be considered during microbiome development. Temperature, drought and excessive moisture can influence microbial colonization and activity. A microbial consortium that performs well under controlled conditions may not show the same performance in agricultural soils. Therefore, field validation under different soil and climatic conditions is essential. Another important area is integration of microbiome manipulation with conventional integrated disease management. Microbiome-based approaches should not necessarily replace resistant cultivars, cultural practices or chemical protection. Instead, they can be incorporated with these methods to reduce disease pressure and potentially decrease dependence on chemical pesticides.

Conclusion

Plant microbiomes represent an important and relatively new resource for sustainable plant disease management. Beneficial microorganisms can suppress pathogens through competition, antimicrobial activity, nutrient limitation and stimulation of plant defence. Manipulation of microbial communities through agronomic practices, microbial inoculants, enrichment of beneficial populations and synthetic microbial communities provides several opportunities for improving crop health. The development of reliable microbiome-based technologies will require a better understanding of microbial community assembly, host–microbe communication and interactions among beneficial microorganisms and pathogens. Recent advances in sequencing, metabolomics, computational biology and synthetic community design are providing tools to move from empirical microbial applications towards more targeted microbiome manipulation. For practical disease management, the most promising approach is likely to involve integration of microbiome manipulation with host resistance, biological control and appropriate agronomic practices. Such an integrated strategy can improve disease suppression while supporting soil health and reducing dependence on chemical inputs. Continued field-based research will be essential for translating microbiome research into consistent and economically viable disease-management technologies.

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How Gen Z is Transforming Modern Agriculture

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Abstract

Agriculture remains fundamental to global food and nutritional security, yet the sector faces mounting challenges from climate change, soil degradation, water scarcity, biodiversity loss, and labour shortages. Generation Z (Gen Z), born amid rapid advances in digital technology, artificial intelligence, and connectivity, is emerging as a pivotal force capable of accelerating agriculture's transition toward a knowledge-based, climate-resilient, and sustainable system. This paper reviews the ways in which Gen Z's digital literacy and entrepreneurial orientation are reshaping modern farming, with emphasis on the adoption of precision agriculture tools such as unmanned aerial vehicles, remote sensing, geographic information systems, and Internet of Things-based sensors for real-time crop and resource monitoring. It further examines the role of smart farming systems, including automated irrigation, variable-rate technology, and predictive analytics, in improving input-use efficiency and farm resilience. The paper also discusses Gen Z's potential contribution to climate-smart and regenerative agriculture, including natural farming inputs such as Jeevamrit and Beejamrit, conservation tillage, cover cropping, and organic farming practices that restore soil health and sequester carbon. The review concludes that by integrating digital innovation with ecological stewardship, Gen Z can drive a new agricultural revolution that secures livelihoods, strengthens food systems, and builds a more sustainable future for farmers worldwide.

Keywords: Generation Z; Precision agriculture; Smart farming; Climate-smart agriculture; Regenerative agriculture; Natural farming; Digital technology; Sustainability

1. Introduction

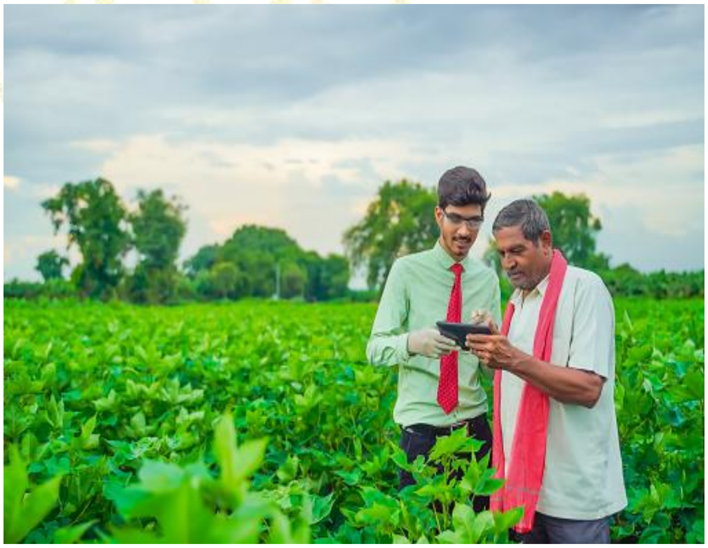
Agriculture constitutes the foundation of global food and nutritional security while providing raw materials, employment, and livelihood opportunities for billions of people worldwide. Despite significant technological advancements, the sector is confronted with multiple challenges, including climate change, land degradation, declining soil fertility, water scarcity, biodiversity loss, increasing production costs, and labour shortages. These constraints threaten agricultural productivity and sustainability, particularly in developing countries. Simultaneously, Generation Z (Gen Z) is emerging as a technologically proficient and environmentally conscious workforce. Their digital literacy, innovative thinking, and entrepreneurial orientation position them as key stakeholders capable of accelerating the transformation of conventional agriculture into a knowledge-based, climate-resilient, and sustainable production system.

Generation Z generally comprises individuals born between 1997 and 2012 who have grown up in an era characterized by rapid advances in information and communication technologies (ICT), artificial intelligence (AI), cloud computing, and digital connectivity. Their familiarity with data-driven technologies, mobile applications, automation, and social media enables them to rapidly adopt and disseminate innovative agricultural practices.

Consequently, Gen Z represents a valuable human resource for promoting technological modernization and strengthening agricultural resilience under changing climatic and socio-economic conditions (Benítez-Márquez *et al*., 2022).

2. Digital Technologies and Precision Agriculture

The integration of advanced technologies into agricultural production systems represents one of the most significant contributions Gen Z can make to modern agriculture. Precision agriculture technologies, including unmanned aerial vehicles (UAVs), remote sensing, geographic information systems (GIS), global positioning systems (GPS), Internet of Things (IoT)-based sensors, and artificial intelligence, facilitate real-time monitoring of crop growth, nutrient status, pest and disease incidence, and water requirements. UAVs equipped with multispectral and hyperspectral imaging



systems enable early detection of biotic and abiotic stresses, while AI-driven decision-support systems improve the precision of irrigation, fertilization, and crop protection practices. Furthermore, mobile-based digital advisory platforms provide real-time weather forecasts, market intelligence, and crop management recommendations, thereby enhancing farm productivity, input-use efficiency, and economic returns (Tsouros *et al.,* 2019; Sharma *et al.,* 2021).

3. Smart Farming and Precision Agriculture Systems

Another important area where Gen Z can contribute is the adoption of precision and smart farming systems. Smart agriculture integrates sensor networks, satellite observations, weather forecasting, big data analytics, and machine learning algorithms to optimize farm management decisions. Soil moisture sensors and automated irrigation systems improve water-use efficiency by applying irrigation according to crop requirements, whereas variable-rate technology enables site-specific nutrient application, thereby minimizing fertilizer losses and environmental contamination. Predictive analytics further assist in yield forecasting, disease surveillance, and risk assessment, improving the resilience and profitability of agricultural production systems (Dhanaraju *et al*., 2022).

4. Climate-Smart, Regenerative, and Natural Farming Approaches

Climate change has emerged as one of the most critical challenges affecting global agricultural sustainability. Increasing temperatures, erratic precipitation patterns, recurrent droughts, floods, and the emergence of new pests and diseases adversely influence crop productivity and food security. In this context, Gen Z can facilitate the transition towards climate-smart and regenerative agricultural systems. Natural farming, regenerative agriculture, and organic farming represent complementary approaches that promote ecological sustainability while maintaining agricultural productivity. Natural farming emphasizes the use of on-farm biological inputs, such as *Jeevamrit*, *Beejamrit* (Patel *et al.,* 2024), mulching, and crop diversification, thereby reducing dependence on synthetic agrochemicals.

Regenerative agriculture focuses on restoring soil ecosystem functions through conservation tillage, cover cropping, crop rotation, integrated crop-livestock systems, and agroforestry, leading to enhanced soil organic carbon sequestration, microbial diversity, nutrient cycling, and water-holding capacity. Organic farming relies on ecological processes, biofertilizers, compost, green manures, and biological pest management to produce safe and environmentally sustainable food. The integration of these agroecological approaches with digital technologies can simultaneously enhance resource-use efficiency, climate resilience, environmental sustainability, and long-term agricultural productivity (Newton *et al.,* 2020).

5. Conclusion

Gen Z has the knowledge, energy, and technological skills needed to transform agriculture. By promoting smart farming, sustainability, innovation, entrepreneurship, and digital communication, they can address many of the challenges facing the agricultural sector today. Agriculture is not just about growing food; it is about securing the future of humanity. If Gen Z actively participates in this field, they can bring a true revolution in agriculture and build a more productive, sustainable, and prosperous future for farmers and society as a whole.

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Processing and Nutritional Value of Apple Ber Fruit Leather

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Introduction

Ber (*Ziziphus mauritiana)* belonged to the family Rhamnaceae that consist of 45 genera and 550 species. It is widely distributed in tropical and subtropical climate in the world. (Mukhtar et al., 2004). Ber has been recognized as a useful edible fruit since antiquity in India. There are two distinct groups of ber found in India (1) Chinese ber (Ziziphus jujube), is an upright tree of 10 m height, bearing dark red fruit. (2) Indian ber (*Ziziphus mauritiana*) is spreading tree having drooping branches with its leaves rusty on lower surface and it is green to yellow leaves and fruits (Pareek, 2001)

Apple Ber is a Thailand mixture ber. The essence of these ber is Sweet, Crispy & Juicy. The heaviness of every plum is around 100-125gm. It appears to be like green Apple. That is the reason it named as apple plum or apple ber. Its farming is currently trending fruit farming. It has lots of advantages over traditional Plume farming. It can be used for the preparation of murabba, leather, chutney, squash or nectar and ready to serve.

Medicinal Properties

Ber is one of the oldest Indian fruits and considered as "Wonder fruit for health" because of its unique qualities. It has played an important therapeutic role from time immemorial and is frequently recommended for its synergic effect in both the Ayurveda and Unani system of medicine it is a rich source of vitamin c and its content as compared apple fruit. (Meena et al., 2009). There is large number of traditional uses that are not necessarily base on knowledge of constituents. According to Ayurveada, the fruit is sour and sweet and cooling, a cures coughs biliousness and headache. Fruit is employed as an antidote poisoning, abdominal pain in pregnancy and externally in poultice an application for wounds (Preeti and Tripathi, 2014).

Nutritional Composition

Nutritional Composition of Apple Ber (per 100g edible portion)

Nutrient	Amount
Moisture (%)	75-85
Energy (kcal)	70-90
Carbohydrates (g)	15-20
Protein (g)	0.8-1.2
Fat (g)	0.1-0.3
Dietary Fiber (g)	0.5-1.5
Vitamin C (mg)	60-120
Vitamin A (IU)	Trace
Potassium (mg)	250-400
Calcium (mg)	20-30
Phosphorus (mg)	20-25
Iron (mg)	0.5-1.5
Ash (g)	0.3-0.8

Leather

Fruit leathers are fruit base dehydrated product. They are chewy and tasty dried slabs made by putting fruit pulp into a mouldy surface. On drying it is put out and rolled. It has given the name due to its leathery appearances. Making leather benefits, in utilizing less sugar and more fruit Flavors, useful for diabetic and health-conscious consumers. Leather can be made from individual and mixed fruit in any proportion. It can be prepared from fresh, frozen and canned fruit. Drying of fruit leather involves removing of moisture, thus microbes can't grow. It also inactivates enzymatic activities. Moisture reduction makes it shrinked to occupy less space and facilitate transportation.

Preparation of Apple Ber Leather

Step 1- Selection of Fruits: Fully ripe, healthy, and uniform apple ber fruits are selected.

Step 2- **Washing and Sorting:** Fruits are washed thoroughly to remove dirt and impurities.

Step 3- Pulp Extraction: Seeds are removed and pulp is extracted using a pulper or manually.

Step 4- Formulation: Common ingredients added-

Step 5- Heating: The pulp mixture is heated to dissolve sugar and ensure uniform mixing.

Step 6- Spreading: The prepared pulp is spread uniformly (5–8 mm thickness) on trays lined with butter paper.

Step 7- Drying: Drying is done using the cabinet dryer (50-60°C), Sun drying or room temperature drying, drying continues until moisture reduces and a leathery texture form.

Step 8- Cutting and Packaging: The dried sheet is cut into desired shapes and packed in airtight materials.

Storage and Shelf Life of Apple Ber Leather

Storage is essential to maintain the quality and shelf life of apple ber leather. The product should be stored under the different condition:

- Ambient temperature (20-25°C): 3-6 months.
- Refrigerated storage (4-10°C): 6-9 months.
- Vacuum packaging: 9-12 months.

Conclusion

Apple ber leather (*Ziziphus mauritiana*) represents an effective value-added product that combines the nutritional benefits of fresh ber with improved shelf life and consumer convenience. The conversion of ber pulp into leather through standardized processing techniques, including pulping, formulation, controlled drying, and appropriate packaging, helps minimize post-harvest losses while maintaining desirable quality attributes. Ber leather is a rich source of carbohydrates, dietary fibre, vitamin C, minerals, phenolic compounds, and antioxidants, making it a nutritious functional snack. Product quality is influenced by factors such as fruit maturity, ingredient formulation, drying conditions, and storage environment. Blending ber with other fruits has also been reported to improve texture, flavour, and overall acceptability. With increasing demand for natural and minimally processed foods, ber leather has considerable potential for commercial production and market expansion. Future research should focus on optimizing processing technologies, improving nutrient retention, evaluating storage stability, and developing innovative formulations to enhance the nutritional and functional properties of ber leather and support large scale production and market acceptance.

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Traditional Community Healthcare System of Tribal-folk

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Abstract

This article highlights Traditional Community Healthcare Providers (TCHPs) and their challenges. India is the birthplace of Ayurveda, Yoga & Naturopathy, Unani, Siddha, and Homeopathy (AYUSH), with a continuous practice for millennia. Increasing public awareness of natural healthcare is driving demand for AYUSH products, fostering a dynamic market ripe for innovative businesses in the sector. The AYUSH industry in India is undergoing remarkable growth and is projected to grow from US$ 43.3 billion in 2024 to US$ 200 billion by 2030. The AYUSH healthcare delivery system in India is bifurcated into public and private sectors. The public sector focuses on promoting and providing access to AYUSH treatments through government institutions and centers across the country. On the other hand, the private sector plays a significant role in offering a wide range of AYUSH services, including specialized treatments, wellness programs, and herbal products. The North Eastern States will play an important role in this sector. North East India is a region rich in traditional medicine and healing practices. Many of these traditional practices have been incorporated into modern healthcare, making it a unique blend of traditional and modern healthcare practices. The region is also known for its indigenous medicinal plants and herbs, which are used in the treatment of various ailments. Some of the common medicinal and aromatic plants such as *phyllanthus embillica, phyllanthus ameras saraka asoka, aegle marmelos, ocimum, achorus, aloe vera, azadirachta indica* etc are widely found in the North Eastern Hill Region. Among the North Eastern states, Meghalaya and its three major tribes; Garo, Khasi and Jaintia, as well as plain people of West Garo Hills, have evidently rich traditional medicinal knowledge systems. Many initiatives are being taken by the government for research and development, setting up of institutions, and certification of Traditional Community Healthcare Providers (TCHP).

Keywords: Traditional healthcare, North Eastern Hill Region, Medicinal and Aromatic plants.

Introduction

Before the introduction of modern science, technological advancement, and allopathic treatment in serving humanity, India witnessed ayurvedic era of the healthcare system. The basic ideology of the system is that health and wellness depend on a delicate balance between the mind, body, spirit and environment, and places great emphasis on preventive strategies rather than curative ones. In this system, plant herbs, their leaves, roots, and stems are the key source of medicine. Later, Yoga & Naturopathy, Unani, Siddha, and Homeopathy were introduced (Tiwari *et al.,* 2021). Now, as a whole, the AYUSH industry in India is undergoing remarkable growth, fueled by escalating consumer interest in traditional medicine, bolstered governmental support, and a burgeoning export market, heralding its significance in shaping India's healthcare and wellness domain. The AYUSH healthcare delivery system in India is bifurcated into public and private sectors. The public sector focuses on promoting and providing access to AYUSH treatments through government institutions and centers across the country.

On the other hand, the private sector plays a significant role in offering a wide range of AYUSH services, including specialized treatments, wellness programs, and herbal products (https://www.ibef.org/industry/ayush). In both cases, north-eastern states play an important role in the promotion of AYUSH due to it’s reach medicinal bio-resources and ethnomedicinal practices. The ethnomedicinal practitioners are known as Traditional Community Health practitioners. These practitioners use their indigenous knowledge for the treatment of people and animal.

Ethno-medicinal treatment in Meghalaya

Northeast India holds about 65.45% of its total geographical area under forests, accounting for roughly 24.22% of India's total forest cover despite occupying less than 8% of the country's land NESAC 2023). https://nesac.gov.in/scientific-programmes/remote-sensing-and-gis/forestry-and-ecology/. Forests function as living pharmacies supplying herbs, shrubs, climbers, and trees used to treat fever, digestive disorders, wounds, respiratory infections, arthritis, and skin diseases. Common medicinal plants include Centella asiatica, ginger, turmeric, Acorus calamus, and various orchids and ferns unique to the Eastern Himalayas. The ethnomedicinal treatment is followed by the three major tribes of Meghalaya as follows.

Garos: The Garo tribe, primarily inhabiting the Garo Hills of Meghalaya, possesses rich traditional ethnomedicinal knowledge closely linked with forest ecosystems and indigenous healing practices.

The Garos rely extensively on locally available medicinal plants for treating common ailments such as fever, skin infections, digestive disorders, wounds, and respiratory problems. Plants like Centella asiatica, Zingiber officinale, Curcuma longa, and Clerodendrum colebrookianum are widely used in herbal preparations, decoctions, and poultices.

Khasi: The Khasi people of Meghalaya in North-East India possess a rich tradition of ethnomedicinal knowledge closely linked to their forest-based lifestyle and sacred ecological beliefs. Traditional healers, locally known as nong ai dawai, utilize diverse medicinal plants collected from surrounding hills and sacred groves for treating common ailments such as fever, digestive disorders, skin diseases, respiratory infections, and wounds. The Khasi tribe utilizes a diverse array of over 85 medicinal plants for ethnomedicinal purposes, particularly for traditional bone setting, skin conditions, gastrointestinal issues, and fevers. Key plants often used include *Potentilla fulgens*(diarrhoea), *Zingiber officinale*(cough), and*Cinnamomum tamala*(gastric problems).

Jaintias: The Jaintia tribe, also known as the Pnar people, inhabit the hill regions of present-day Meghalaya and adjoining areas of Assam. Traditionally dependent on forest resources, the Jaintia community possesses rich ethnomedicinal knowledge closely linked with nature and spiritual practices. The tribe uses a wide variety of medicinal plants, with over 40 species commonly employed to treat ailments like diarrhoea, skin infections, diabetes, and injuries. Medicinal plants play an essential role in their primary healthcare system, where local healers utilize leaves, roots, bark, and rhizomes for treating ailments such as fever, stomach disorders, skin infections, wounds, and respiratory problems. Commonly used plants include *Clerodendrum* (hypertension), *Chromolaena odorata* (wound healing), *Allium cepa* (various illnesses), *Hiptage madhablata* (antimicrobial, anti-inflammatory and would healing), *Curcuma longa* (antimicrobial) and *Zingiber officinale* (rhizome).

However, these systems face growing threats from deforestation, climate change, biodiversity loss, cultural assimilation, and the erosion of oral traditions, making documentation and conservation increasingly important.

Challenges in Traditional Healthcare System

- **Limited Documentation:** Most traditional community health practitioners are, though culturally and traditionally rich, educationally disadvantaged. Whatever traditional medicinal knowledge is gathered from their ancestors is technically faced with difficulties in passing it to the next generation or in documentation.

- **Inadequate medicinal plants:** Due to commercial crop production, many species of medicinal plants are extinct or rarely found in the jungles. A forest is the living pharmacy, but jhum cultivation (also known as burn and slash cultivation) highly practiced in the hilly regions, may impact the adequate supply of medicinal plant herbs.

- **Low-cost service:** Traditional Community Healthcare providers believe that it is a service to the community. If commercialized, the plant herb medicine may not work. Due to difficulties in finding for the desired plant herb, now started, charging a minimum fee, which is insufficient to build a proper healthcare service centre and other necessary required tools.

- **Lack of training and certification:** limited training to enhance their traditional knowledge and certification of their art and skills is a major challenge.

Government Initiatives for the Traditional Community Healthcare Practitioner:

For the promotion of the AYUSH sector, the Government of India has taken many initiatives.

1. **Institutions**: Tribal Research Institute, ICMR-National Institute for Tribal Health Research, Central Ayurveda Research Institute (CARI) in Guwahati, the North Eastern Institute of Ayurveda & Homoeopathy (NEIAH) in Shillong, and the North Eastern Institute of Ayurveda & Folk Medicine Research (NEIAFMR) in Pasighat, etc. are the institutions that encourage traditional medicinal usage and research and development.

2. **Tribal Health Care Research Programme (THCRP):** Central Council for Research in Ayurvedic Sciences (CCRAS) has been executing Tribal Health Care Research programme (THCRP) under Tribal Sub Plan (TSP) in identified Tribal dominated villages since 1982. The core objective of the programme is to study the living conditions of tribal people, which includes health-related demography, documentation of folk claims, and free medical health camps.

3. **Poshan Vatikas creation:** Poshan Abhiyaan was launched in the 8th March, 2018. Poshan Vatikas is a part of Mission Poushan help to meet the important dietary diversity gap that has been repeatedly revealed in surveys by providing different fruits, nuts, herbs, medicinal plants, and vegetables round the year. The main objective of introducing the concept of Poshan Vatika is to encourage community members to cultivate local food crops in their backyards. A nutrition garden ensures an inexpensive, regular and handy supply of fresh fruits and vegetables that are basic to good nutrition. Green vegetables and seasonal fruits contain vitamins and minerals that protect against micro-nutrient deficiencies and diseases.

4. **Ekalavya Model Residential Schools (EMRS):** It's a joint effort between the Ministry of Tribal Affairs and the Ministry of Ayush. It's promoting traditional medicinal knowledge support on their campus. This is a blended approach for modern and traditional medicinal systems which targets malnutrition, iron-deficiency anemia, and sickle cell disease.

5. **Tribal Health Research and the Tribal Health Observatory:** The Ministry of Tribal Affairs and ICMR–Regional Medical Research Centre, Bhubaneswar, for the establishment of India's first National Tribal Health Observatory – the Bharat Tribal Health Observatory (B-THO) under Project DRISTI. This collaboration will institutionalize tribe-disaggregated health surveillance, implementation research, and research-driven disease elimination initiatives in tribal districts with a focus on malaria, leprosy, and Tuberculosis, addressing a long-standing national gap in tribal-specific health data, analytics, and evidence-based planning (https://www.pib.gov.in/PressReleasePage.aspx?PRID=2215388®=3&lang=1).

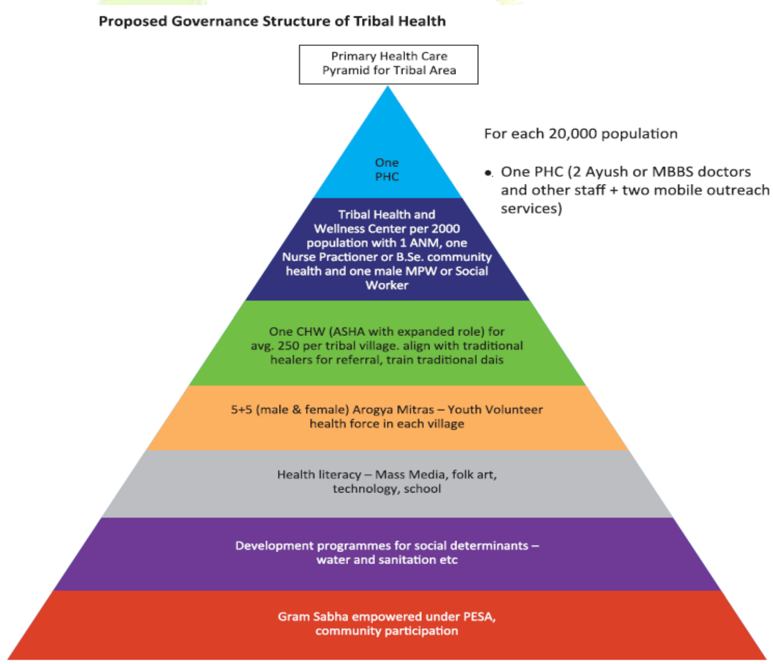

Figure 1: Road map for TCHP

6. **PM-JANMAN:** The objective of the scheme is to enhance the socio-economic conditions of Particularly Vulnerable Tribal Groups (PVTGs)by providing comprehensive development interventions. The scheme focuses on 11 critical interventions across various sectors, including housing, drinking water, healthcare, education, nutrition, livelihood, and electrification, to improve the quality of life for PVTGs. As per healthcare is concerned, strengthening the monitoring of healthcare services through Mobile Medical Units (MMUs) with the usage of technological tools like GPS etc.

7. **Voluntary Certification Scheme for Traditional Community Healthcare Providers (VCSTCHP).** The Voluntary Certification Scheme for Traditional Community Healthcare Providers (TCHPs) seeks to assess and recognize their knowledge and skills against a structured minimum competency framework. The scheme aims to preserve traditional healthcare practices, strengthen service quality, and enhance the confidence and capabilities of TCHPs in delivering community-based care. It also promotes public awareness and enables better integration with government health systems while respecting the autonomy of community traditions.

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Promotion of Low-Cost Integrated Pest Management (IPM) Practices in Chilli Cultivation at Village Level

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Abstract

Chilli (*Capsicum annuum* L.) is an important commercial spice crop that contributes significantly to farmers' income and rural livelihoods in India. However, its productivity is severely affected by insect pests such as *Thrips parvispinus*, *Scirtothrips dorsalis*, aphids, whiteflies, mites and fruit borers. Excessive reliance on chemical pesticides has led to insecticide resistance, pest resurgence, environmental pollution and increased cultivation costs. Low-Cost Integrated Pest Management (IPM) offers an eco-friendly and economically sustainable alternative for effective pest management. The present study assessed farmers' awareness, adoption and constraints regarding low-cost IPM practices through a survey of 150 chilli growers from three villages of Raipur district, Chhattisgarh, during 2025-26. The findings revealed that while awareness of major insect pests and routine crop monitoring was high, adoption of biological control, microbial biopesticides and Economic Threshold Level (ETL) based pest management remained comparatively low. The major constraints included inadequate technical knowledge, limited availability of biological inputs and insufficient extension support. Strengthening farmer training, field demonstrations and village-level extension services can significantly improve the adoption of low-cost IPM practices, thereby reducing pesticide dependence and promoting sustainable, profitable and environmentally friendly chilli cultivation.

Keywords: Chilli, Integrated Pest Management (IPM), Farmer awareness, Adoption, Extension education, Sustainable agriculture, Chhattisgarh.

Introduction

Agriculture is the backbone of rural India, providing livelihoods to millions of farming families. Among horticultural crops, chilli (*Capsicum annuum* L.) is one of the most important

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spice crops due to its high economic value, nutritional significance and industrial uses. India is the world's largest producer, consumer and exporter of chilli, with Chhattisgarh emerging as an important chilli-growing state under diverse agro-climatic conditions.

Despite its importance, chilli cultivation is severely constrained by insect pests such as invasive black thrips (*Thrips parvispinus*), chilli thrips (*Scirtothrips dorsalis*), aphids, whiteflies, yellow mites and fruit borers. Farmers often rely on repeated chemical pesticide applications, which have led to insecticide resistance, pest resurgence, destruction of beneficial insects, environmental pollution and increased production costs.

Low-Cost Integrated Pest Management (IPM) offers a sustainable and eco-friendly alternative by integrating cultural, mechanical, biological, botanical and need-based chemical methods to manage pests below the Economic Threshold Level (ETL). These technologies are particularly suitable for small and marginal farmers as they reduce production costs, conserve natural enemies and promote environmentally safe chilli cultivation.

Recognising the need to promote sustainable pest management, National Service Scheme volunteers implemented a village-level extension programme entitled "Promotion of Low-Cost Integrated Pest Management (IPM) Practices in Chilli Cultivation at Village Level." The programme aimed to create awareness, encourage the adoption of economical and eco-friendly IPM technologies, identify farmers' constraints and strengthen the link between agricultural research and rural communities through extension education and community participation. This study has been conducted based on these objectives:

1. To assess the level of awareness of farmers regarding low-cost IPM practices in chilli cultivation.
2. To promote the adoption of low-cost IPM practices among chilli growers.
3. To identify the major constraints faced by farmers in adopting low-cost IPM practices and obtain their suggestions for improving adoption

Study Area and Methodology

The programme was conducted during 2025–2026 in three villages of Raipur district, Chhattisgarh- Pirda, Dharampura and Serikhedi. A total of 150 chilli growers (50 farmers from each village) were selected randomly. Information was collected through personal interviews using a structured questionnaire and visited to farmers' fields and households to understand their existing pest management practices, create awareness about low-cost IPM technologies and demonstrate practical pest management methods. Various extension approaches were employed, including:

- Farmer interaction meetings
- Field visits
- Practical demonstrations
- Awareness campaigns
- Distribution of educational materials
- One-to-one technical guidance

Major Low-Cost IPM Practices Promoted: The extension programme focused on simple, economical and environmentally friendly pest management technologies, including:

Cultural Practices: Timely field sanitation, removal of pest infested plant parts, crop rotation, balanced fertilizer application, weed management.

Mechanical Methods: Installation of blue sticky traps for thrips, yellow sticky traps for aphids and whiteflies, pheromone traps for fruit borer monitoring, bird perches to encourage insectivorous birds.

Biological Control: Conservation of ladybird beetles, lacewings and spiders, Release of *Trichogramma chilonis*, Use of entomopathogenic fungi such as *Beauveria bassiana*, *Metarhizium anisopliae* and *Lecanicillium lecanii*

Botanical and Microbial Control: Neem Seed Kernel Extract (NSKE 5%), Neem oil spray, *Bacillus thuringiensis* (Bt), *Helicoverpa armigera* Nuclear Polyhedrosis Virus (HaNPV)

Need-Based Chemical Control: Chemical insecticides were recommended only after pest populations reached the Economic Threshold Level (ETL), ensuring judicious and safe pesticide use.

Major Findings

The survey revealed a moderate level of awareness and adoption of low-cost IPM practices among chilli growers. Farmers showed high awareness and adoption of regular crop monitoring, neem-based insecticides, sticky traps and field sanitation. In contrast, awareness and adoption of biological control agents, microbial biopesticides, natural enemy conservation and ETL-based pest management remained comparatively low. The findings indicate that farmers readily adopt simple, affordable and easily accessible technologies, whereas knowledge-intensive IPM components require greater extension support and practical training.

Major Constraints

The adoption of low-cost IPM practices was primarily constrained by lack of technical knowledge, limited availability of biological control agents, inadequate extension support, high cost of quality bio-inputs, lack of practical demonstrations, poor understanding of the Economic Threshold Level (ETL) and limited confidence in biological pest management. These constraints emphasize the need for continuous farmer education, timely access to quality IPM inputs and strengthened extension services to improve the adoption of sustainable pest management practices.

Impact of the Programme

The village-level extension programme positively influenced farmers' knowledge and attitudes towards sustainable pest management. It enhanced awareness of eco-friendly IPM practices, increased the use of neem-based products, sticky traps and regular crop monitoring, strengthened confidence in biological control, reduced reliance on indiscriminate pesticide use, and improved linkages between farmers and agricultural extension agencies. These findings demonstrate that community-based extension programmes can effectively promote the adoption of sustainable pest management technologies and improve village-level agricultural practices.

From Chemical Dependence to Sustainable Pest Management

Insect pests such as thrips, aphids, whiteflies, mites and fruit borers pose serious constraints to chilli production, often prompting farmers to rely heavily on chemical insecticides. However, indiscriminate pesticide use has resulted in insecticide resistance, destruction of natural enemies, environmental pollution and increased production costs. Low-cost Integrated Pest Management (IPM), which integrates cultural, mechanical, biological, botanical and need-based chemical measures, offers an economical and environmentally sustainable alternative for managing pests below the Economic Threshold Level (ETL). Accordingly, the present study was undertaken in Raipur district, Chhattisgarh, to assess farmers' awareness and adoption of low-cost IPM practices and identify the major constraints limiting their wider implementation.

Why Low-Cost IPM Matters More Than Ever

India is the world's leading producer, consumer and exporter of chilli; however, insect pests can cause 80–100% yield losses under severe infestations. Excessive dependence on chemical insecticides has resulted in resistance, pest resurgence, environmental contamination and increased production costs. Low-cost Integrated Pest Management (IPM) offers an affordable and sustainable alternative by integrating cultural, mechanical, biological and need-based chemical approaches, particularly benefiting small and marginal farmers.

Table. Importance of Low-Cost IPM in Chilli Cultivation

Aspect	Key Points
Major insect pests	*Thrips parvispinus*, *Scirtothrips dorsalis*, aphids, whiteflies, yellow mites, tobacco caterpillar and gram pod borer
Major challenges of chemical control	Insecticide resistance, pest resurgence, loss of natural enemies, pesticide residues, environmental pollution and increased production costs
Role of low-cost IPM	Integrates cultural, mechanical, biological and need-based chemical methods for sustainable pest management
Key benefits	Affordable, eco-friendly, reduces pesticide dependence and suitable for small and marginal farmers

Who Are the Farmers Behind the Study?

The socio-economic profile showed that most respondents were:

Table 1. Socio-economic profile of surveyed chilli growers (n = 150)

Indicator	Predominant Category	Percentage
Age	Middle (36–55 years)	54.67
Education	Secondary education	30.67
Landholding	Marginal + Small	60.00
Annual income	Medium	45.33
Farming experience	Medium	50.67
Extension contact	Medium	47.33

Farmers' Awareness of Low-Cost IPM Practices

Table 2. Farmers' awareness regarding low-cost IPM technologies

Awareness Component	Farmers Aware (%)
Major insect pests	94.67
Economic losses	90.67
Neem-based insecticides	84.00
Sticky traps	78.67
ETL concept	64.00
Natural enemy conservation	60.00
Biological control	58.67
Microbial biopesticides	54.67

Awareness Does Not Always Translate into Adoption

Although awareness was relatively high, adoption remained moderate. Regular crop monitoring (84.00%), neem-based insecticides (76.00%), sticky traps (72.00%), and field sanitation (69.33%) were the most widely adopted practices. In contrast, adoption of ETL-based spraying (58.67%), pheromone traps (54.67%), natural enemy conservation (49.33%), and biological control agents (45.33%) was comparatively low. Overall, 45.33% of farmers showed medium adoption, while 29.34% and 25.33% exhibited high and low adoption levels, respectively, indicating the need for continued technical support and practical demonstrations.

Table 3. Adoption of low-cost IPM practices

Practice	Adoption (%)
Regular field monitoring	84.00
Neem-based insecticides	76.00
Sticky traps	72.00
Field sanitation	69.33
ETL-based spraying	58.67
Pheromone traps	54.67
Natural enemy conservation	49.33
Biological control	45.33

Low-Cost IPM Practices Farmers Can Easily Adopt

The survey identified several affordable technologies suitable for village-level promotion.

- ✓ **Intercropping** with onion, coriander, garlic and legumes increases biodiversity and naturally suppresses pest populations.
- ✓ Marigold serves as an excellent trap crop against *Helicoverpa armigera* when planted at a 10:1 chilli to marigold ratio.
- ✓ **Bird perches** encourage insectivorous birds that naturally reduce caterpillar populations.
- ✓ **Blue sticky traps** effectively monitor thrips, whereas yellow traps help detect aphids and whiteflies. Pheromone traps enable timely management of fruit borers before economic damage occurs.
- ✓ **Botanical pesticides** such as Neem Seed Kernel Extract (5%) and neem oil remain economical and environmentally safe options for controlling sucking pests.
- ✓ **Biological control** agents-including *Chrysoperla*, ladybird beetles, *Trichogramma chilonis* and entomopathogenic fungi provide sustainable pest suppression while conserving ecological balance.

Table 4. Major constraints in adopting low-cost IPM

Constraint	Percentage
Lack of technical knowledge	74.67
Non-availability of biological inputs	70.00

Constraint	Percentage
Inadequate extension support	65.33
High cost of bio-inputs	64.00
Lack of practical training	62.67
Limited ETL knowledge	58.67
Lack of confidence in biological control	56.00

Strategies to Enhance IPM Adoption

Enhancing farmer training, on-farm demonstrations and extension programmes is essential to improve IPM adoption. Timely availability of quality biological control agents, microbial biopesticides and sticky traps, supported by mobile-based advisories, WhatsApp groups and seasonal pest alerts, can facilitate informed decision-making. Recognizing progressive IPM farmers through village-level demonstrations and awards may further encourage community-wide adoption.

Why This Matters Beyond Chilli Fields

The benefits of low-cost IPM extend beyond pest management by reducing pesticide dependence, improving food safety and farmers' health, conserving natural enemies and biodiversity, delaying insecticide resistance, lowering production costs and enhancing farm profitability. Consequently, wider adoption of IPM contributes to food security, environmental conservation and sustainable rural livelihoods.

Conclusion

The study demonstrated that village-level promotion of low-cost Integrated Pest Management (IPM) effectively enhances sustainable chilli cultivation. Most farmers exhibited a moderate level of awareness (56.00%) and adoption (45.33%) of IPM practices, with greater adoption of regular crop monitoring, neem-based pesticides, sticky traps and field sanitation than biological control, microbial biopesticides and ETL-based pest management. Inadequate technical knowledge, limited availability of biological inputs, insufficient extension support and lack of practical training were the major barriers to adoption. Strengthening farmer training, field demonstrations and extension services can significantly improve the uptake of eco-friendly IPM technologies. The findings demonstrate that community-based NSS extension programmes can effectively reduce pesticide dependence, conserve beneficial organisms, lower production costs and promote sustainable, profitable and environmentally sound chilli production.

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Understanding Farmers' Adoption of Crop Residue Management Practices: Barriers Beyond Awareness

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Abstract

Crop residue burning continues to be prevalent in India despite warnings for decades. This article discusses a field survey of 150 farmers in three villages of Raipur district in Chhattisgarh on their knowledge and adoption of Crop residue management (CRM) practices. Findings indicate a shocking gap: despite being aware of the environmental degradation caused by burning, 93.33% of farmers still do not practice sustainable alternatives like mulching, composting or Happy Seeder technology. Structural constraints, costly machinery, delayed subsidies, and limited technical training come to dominate the list of barriers, dwarfing attitudinal resistance. The study posits that closing this awareness-adoption gap must involve intervention on the infrastructure and financial levels, rather than more general environmental messages, lessons that go beyond Chhattisgarh's fields.

Keywords: Crop residue burning; Crop residue management (CRM); Farmer awareness; Technology adoption; Chhattisgarh.

A Familiar Haze, a Familiar Habit

Every year, as the paddy fields of central India are stripped bare after harvest, a thin grey haze descends upon villages and towns. It is the smell of stubble burning, a practice so ingrained into Indian farming that it is invisible to the people who practice it even as it becomes more visible on satellite maps and air-quality indices. For years, agricultural scientists have warned of the price to be paid for this quick, cheap method of clearing fields between crops: depleted soils, dirty air and an increasing contribution to climate change. But farmers continue to use these matches anyway because the alternative is often too hard, too expensive, or too little understood.

A recent field study by three villages of Raipur district in Chhattisgarh - Dharampura, Pirda and Nakati, set out to unravel this paradox. Interviewing 150 farmers face-to-face on their own farms and in their homes during the 2025–26 season, the study asked a deceptively simple question: how much do farmers actually know about crop residue management, and how much of that knowledge translates into action? The answers reveal a story that is less about ignorance and more about the gap between awareness and access.

Methodology at a Glance

Raipur district was chosen for the study on grounds of accessibility, and four villages were shortlisted, of which Dharampura, Pirda, and Nakati were randomly selected. Fifty farmers were interviewed in each village 150 in total through structured personal interviews conducted in a relaxed, confidential setting designed to encourage candid responses about both what farmers knew and what they actually practised on their land.

Why Residue Management Matters More Than Ever

India's agricultural success story built on mechanization, irrigation, and high-yielding varieties has an unglamorous byproduct. Intensive cropping systems such as rice-wheat and rice-chickpea rotations generate hundreds of millions of tonnes of crop residue every year, according to estimates from the Indian Council of Agricultural Research. Rice straw, wheat straw, maize stover, and sugarcane trash are not waste in any meaningful sense; they are reservoirs of nitrogen, phosphorus, potassium, sulphur, and organic carbon that, if returned to the soil, could sustain fertility for generations.

Burned instead, this biomass releases its nutrients into the air rather than the earth. Nitrogen and sulphur volatilise and vanish; the carbon that could have built soil organic matter goes up as carbon dioxide, methane, and nitrous oxide, alongside particulate matter fine enough to penetrate deep into human lungs. The widespread practice of open-field crop residue burning is illustrated in Figure 1. The Central Pollution Control Board has repeatedly documented seasonal pollution spikes tied to residue burning, and the resulting respiratory and cardiovascular health burden extends far beyond the fields themselves, into cities and towns downwind. Over time, repeated burning also degrades soil structure and water-holding capacity, pushing farmers toward greater reliance on synthetic fertilisers and raising both production costs and environmental risk. The widespread practice of open-field crop residue burning is illustrated in Figure 1.

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Figure 1. Open-field burning of crop residues following harvest, a common practice contributing to air pollution, nutrient loss, and greenhouse gas emissions.

The alternative is not simply 'don't burn' it is a suite of technologies and practices collectively known as Crop Residue Management, or CRM. These fall into two broad families. In-situ management keeps residue on or in the field: mulching the surface, incorporating stubble into the soil, or sowing the next crop directly through the residue using machines like the Happy Seeder, Super Straw Management System, zero-till drills, and rotavators. Ex-situ management removes the residue for use elsewhere composting, vermicomposting, livestock fodder, mushroom cultivation substrate, packaging material, or biomass energy. Both pathways offer farmers a way to turn a disposal problem into an asset, but both also demand knowledge, equipment, and sometimes capital that not every farmer has in equal measure. An example of in-situ crop residue management through paddy straw mulching in chickpea is presented in Figure 2.

Figure 2. In-situ crop residue management through paddy straw mulching in chickpea for improved soil conservation and sustainable residue utilization.

Who Are the Farmers Behind the Numbers?

To understand adoption patterns, the study first mapped the socio-economic profile of its 150 respondents. The picture that emerges is of a farming community in its productive prime, but with limited financial cushioning. More than half (54.67%) of respondents fell into the middle-age bracket of 36 to 55 years, suggesting a population actively engaged in day-to-day decision-making rather than one dominated by either very young or retired landholders.

Education levels were moderate: just 12% were illiterate, while the largest single group (30.67%) had completed secondary schooling, and a further 22.67% had higher secondary education. Landholding told a more constraining story a full 60% of respondents were classified as marginal (up to 1 hectare) or small (1–2 hectares) farmers, the two categories least able to absorb the upfront cost of CRM machinery. Annual income clustered in the 1–3 lakh range for 45.33% of respondents, with just over a quarter earning above 3 lakh. Farming experience was substantial half the sample had between 11 and 25 years in the field and contact with agricultural extension services was 'medium' for 47.33% of farmers, but still low for nearly 30%. Taken together, these figures sketch a population with real farming knowledge and moderate education, but constrained by small landholdings, mid-range income, and inconsistent access to extension advice a combination that, as the results below show, shapes behaviour more than attitude does. The socio-economic profile of the surveyed farmers is summarized in Table 1.

Table 1: Socio-economic snapshot of the 150 surveyed farmers

Socio-economic	Indicator Category	Share of Farmers
Age	Middle-aged (36–55 yrs)	54.67%
Education	Secondary schooling	30.67%
Landholding	Marginal + small (≤2 ha)	60.00%
Annual income	1–3 lakh (medium	45.33%
Farming experience	11–25 years (medium)	50.67%
Extension contacts	Medium level	47.33%

What Farmers Know: A Story of Uneven Awareness

On the question of awareness, the news is largely encouraging with important caveats. An overwhelming 93.33% of farmers understood that residue burning contributes to environmental pollution, and 88% were aware of its harmful effects more broadly. Knowledge of nutrient loss from burning was also high, at 80%. These are not marginal figures; they indicate that the core environmental message about stubble burning has reached deep into rural Chhattisgarh.

Where awareness thins out is in the specifics the tools and institutional support that could actually change behaviour. Only 46.66% of farmers had heard of Happy Seeder technology, and just half (50.67%) knew about bio-decomposers, the microbial sprays used to accelerate residue breakdown in the field. Awareness of government subsidy schemes stood at 61.33%, meaning nearly four in ten farmers had no idea that financial support for CRM equipment might even exist. Awareness of mulching benefits (73.33%), composting (70%), and mushroom cultivation using paddy straw (65.33%) fell in between solidly promoted concepts, but not yet universal knowledge. When these individual indicators were combined into an overall awareness score, 54.67% of farmers landed in the 'medium' category, with 26.66% classified as highly aware and 18.67% still in the low-awareness bracket. The pattern is clear: farmers grasp the 'why' of residue management far better than the 'how.' They know burning is bad. Fewer know what, precisely, to do instead and even fewer know that help exists to do it. Statement-wise awareness levels of farmers regarding CRM practices are presented in Table 2.

Table 2: Statement-wise awareness of CRM practices (n = 150)

Awareness Statement	% Aware
Environmental pollution from burning	93.33%
Harmful effects of burning (general)	88.00%
Soil nutrient loss due to burning	80.00%
Mulching benefits	73.33%
Composting of residues	70.00%
Mushroom cultivation using straw	65.33%

Government subsidy schemes	61.33%
Bio-decomposers	50.67%
Happy Seeder technology	46.66%

What Farmers Actually Do: Adoption Lags Behind Understanding

If awareness were the whole story, residue burning would already be in retreat. But knowing and doing are separated by a wide and familiar gulf. When the same 150 farmers were asked about their actual practices, adoption of CRM technologies came in noticeably lower than corresponding awareness levels.

Mulching was the most widely adopted practice, used by 48% of farmers a relatively low-cost, low-complexity option that requires no specialised machinery. Mushroom cultivation using straw followed at 40%, offering farmers a direct income stream alongside residue disposal. Compost preparation was practised by 36% of respondents. Further down the list, the more capital-intensive and technically demanding options lagged: bio-decomposer use stood at just 25.33%, and in-situ incorporation using Happy Seeder or manual methods was adopted by only 22.67% of farmers despite Happy Seeder being one of the most heavily promoted CRM technologies in policy circles.

Perhaps most tellingly, 30.67% of farmers reported still practising partial burning, and 18.67% admitted to complete burning of residues. When aggregated into an overall adoption index, only 20% of farmers achieved a 'high' adoption score, while 45.33% sat at 'medium' and a substantial 34.67% remained at 'low' adoption. The gap between the 93.33% who know burning pollutes the air and the 18.67% who still burn everything anyway is the central tension this study lays bare: understanding a problem and having the means to solve it are two very different things.

The Real Barriers: Time, Money, and Machines

Ask farmers why they still burn despite knowing better, and the answers are strikingly practical rather than ideological. The single largest constraint identified was the tight turnaround between harvesting one crop and sowing the next cited by 80% of respondents. In rice-wheat systems especially, the window between crops can be a matter of days, and residue-heavy fields slow down sowing operations considerably unless the right machinery is on hand immediately.

Machinery cost came a close second: 78.67% of farmers pointed to the high price of CRM equipment as a barrier, and 73.33% said machines simply were not available when needed, even where custom hiring centres exist on paper. Labour shortage compounded the problem for 61.33% of respondents, while 68% cited a lack of subsidy or delays in subsidy disbursement, and 57.33% pointed to insufficient technical knowledge about how to actually operate or benefit from CRM technologies. None of these are attitude problems. They are supply-chain, financing, and logistics problems. The major constraints reported by farmers in adopting CRM practices are summarized in Table 3. A farmer who has ten days to clear a field, cannot book a Happy Seeder in time, and has watched a promised subsidy fail to arrive on schedule will burn the stubble not because they don't understand the consequences, but because the alternative, in that moment, is not actually available to them.

Table 3. Major constraints reported by farmers in adopting CRM *(n = 150)*.

Constraint	% Reporting
Time constraint between crops	80.00%
High cost of machinery	78.67%
Non-availability of machinery on time	73.33%
Lack of subsidy / delayed subsidy	68.00%
Labour shortage	61.33%
Lack of technical knowledge	57.33%

Turning Awareness into Action

The study's recommendations follow directly from this diagnosis. Rather than more general awareness campaigns which the data suggest have already achieved considerable reach the emphasis falls on removing structural and financial friction. Strengthening custom hiring centres so that Happy Seeders, mulchers, and Super Straw Management Systems are actually available within the narrow sowing window is a recurring theme. So is ensuring subsidy schemes disburse funds without the delays that currently undermine their credibility.

Equally important is closing the knowledge gap around specific technologies rather than general environmental harm. Field demonstrations, farmer field schools, and hands-on training in bio-decomposer application or composting technique could move awareness from the abstract ('burning is bad') to the operational ('here is exactly what I do instead'). The study also points to farmer cooperatives and shared machinery ownership as a way for marginal and small landholders 60% of the sample to access equipment they could never justify buying individually. Finally, recognising and publicly rewarding early adopters may harness the same peer-influence dynamics that currently spread burning as the default, redirecting social pressure toward sustainable alternatives instead.

Mass media, mobile messaging, and farmer fairs are recommended as low-cost channels for closing the subsidy-awareness gap specifically since more than a third of farmers currently do not know that financial assistance for CRM equipment exists at all. Combined with more frequent village visits by extension personnel, these channels could shift the 'medium awareness' majority toward the 'high awareness' tier much faster than blanket public messaging alone.

Beyond the Field: Why This Matters to Everyone

The consequences of this awareness-adoption gap extend well past the villages surveyed. Residue burning's particulate matter and greenhouse gas emissions do not respect administrative boundaries; they drift into cities, contribute to regional air-quality crises, and add to the atmospheric carbon load driving climate change. Conversely, every hectare where residue is retained as mulch or incorporated into soil represents a small increment of carbon sequestration, improved water retention, and reduced fertiliser dependence benefits that ripple outward into food security and rural resilience against increasingly erratic weather.

The Chhattisgarh study, small in geographic scope but rich in detail, offers a template for thinking about this problem elsewhere in India. It suggests that the next phase of the fight against stubble burning will not be won primarily through more posters and pamphlets about air pollution farmers have largely absorbed that message already. It will be won through custom hiring centres that actually have machines on the day they're needed, subsidies that arrive before the sowing window closes, and training that teaches not just why residue management matters, but exactly how to do it, practice by practice, tool by tool.

Conclusion

This study demonstrates that the persistence of crop residue burning in rural Chhattisgarh is not a failure of environmental understanding but a failure of enabling infrastructure. Farmers overwhelmingly recognise the ecological and health costs of burning, yet adoption of sustainable alternatives such as mulching, composting, bio-decomposers, and Happy Seeder technology remains constrained by narrow sowing windows, high machinery costs, delayed subsidies, and uneven technical support challenges concentrated most heavily among the marginal and small landholders who dominate the sample. Bridging this awareness-adoption divide will require less emphasis on generic public messaging and far greater investment in accessible custom hiring centres, timely subsidy disbursement, hands-on technical training, and cooperative machinery-sharing models for resource-poor farmers. If these structural barriers are addressed, the considerable environmental knowledge farmers already possess can finally translate into practice reducing air pollution, rebuilding soil health, and strengthening the long-term resilience and sustainability of India's farming systems.

Source: Field survey of 150 farmers across Dharampura, Pirda, and Nakati villages, Raipur district, Chhattisgarh (2025–2026); data on socio-economic profile, awareness, adoption, and constraints regarding crop residue management practices.