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BERRY CULTIVATION IN INDIA: IMPORTANCE, CULTIVATION TECHNIQUES, AND FUTURE PROSPECTS

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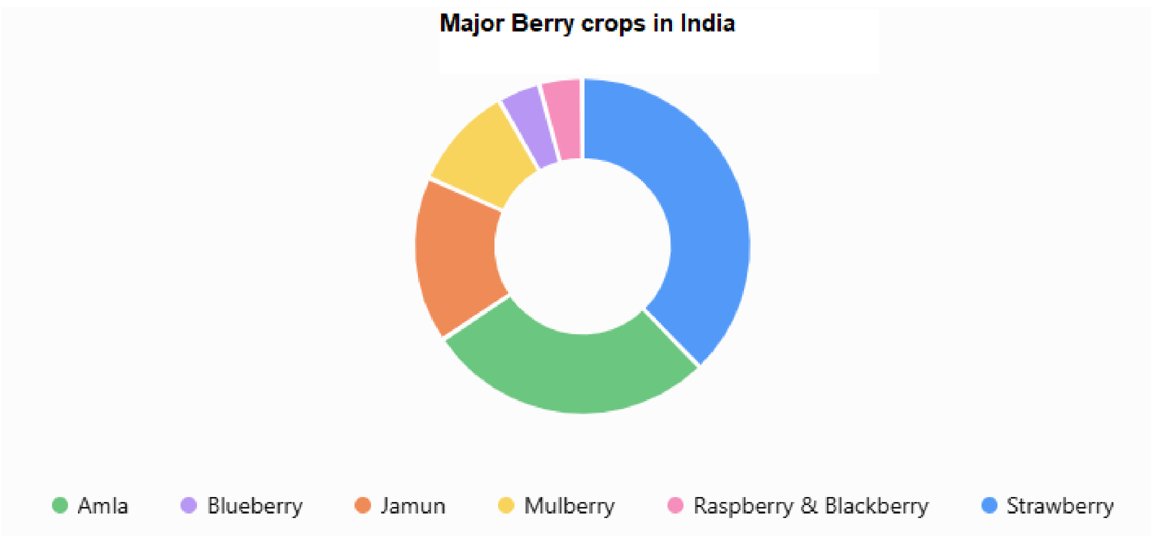
Berry cultivation has gained considerable attention in India over the past decade owing to the increasing demand for nutritious, high-value fruits and the growing awareness of healthy dietary habits. Berries are small, fleshy fruits that are rich in vitamins, minerals, dietary fibre, antioxidants, and phytochemicals, making them an integral part of functional foods. Although India has traditionally cultivated fruits such as mango, banana, and citrus, berries are gradually emerging as a profitable alternative due to their premium market value and expanding domestic and export demand.

The term 'berries' in commercial horticulture includes crops such as strawberry (Fragaria × ananassa), raspberry (Rubus idaeus), blackberry (Rubus fruticosus), blueberry (Vaccinium spp.), mulberry (Morus spp.), gooseberry or amla (Phyllanthus emblica), jamun (Syzygium cumini), and cape gooseberry (Physalis peruviana). Among these, strawberry is the most commercially cultivated berry crop in India, while blueberries and raspberries are gaining popularity in niche markets. Indigenous berry crops like amla and jamun have long been valued in Ayurveda and traditional medicine for their therapeutic properties.



Importance of Berry Cultivation

Berries are recognized worldwide as 'superfoods' because they contain high concentrations of antioxidants, anthocyanins, flavonoids, vitamin C, vitamin E, folate, and dietary fibre. Regular consumption of berries helps reduce the risk of cardiovascular diseases, diabetes, obesity, certain cancers, and age-related disorders by combating oxidative stress and inflammation.

Economically, berry cultivation offers significant opportunities for farmers due to its high market price and relatively quick returns, particularly under protected cultivation. Strawberry starts yielding within four to six months of planting. Berry cultivation also generates employment through nursery raising, harvesting, grading, packaging, processing, and marketing. Value-added products such as jams, jellies, juices, syrups, frozen berries, yoghurts, bakery products, and nutraceuticals further increase profitability.

Cultivation Techniques

Successful berry cultivation depends on selecting suitable varieties, adopting scientific cultivation practices, and ensuring efficient post-harvest management.

Climate and Soil: Most berries perform well in well-drained sandy loam soils rich in organic matter. Strawberry grows best at 15–25°C, while blueberry requires acidic soils (pH 4.5–5.5).

Propagation and Planting: Strawberries are propagated through runners, whereas blueberries, raspberries, and blackberries are propagated through tissue culture, cuttings, or suckers. Raised beds, drip irrigation, and plastic mulching are recommended.

Nutrient and Water Management: Integrated nutrient management using organic manure and balanced fertilizers combined with fertigation through drip irrigation improves productivity.

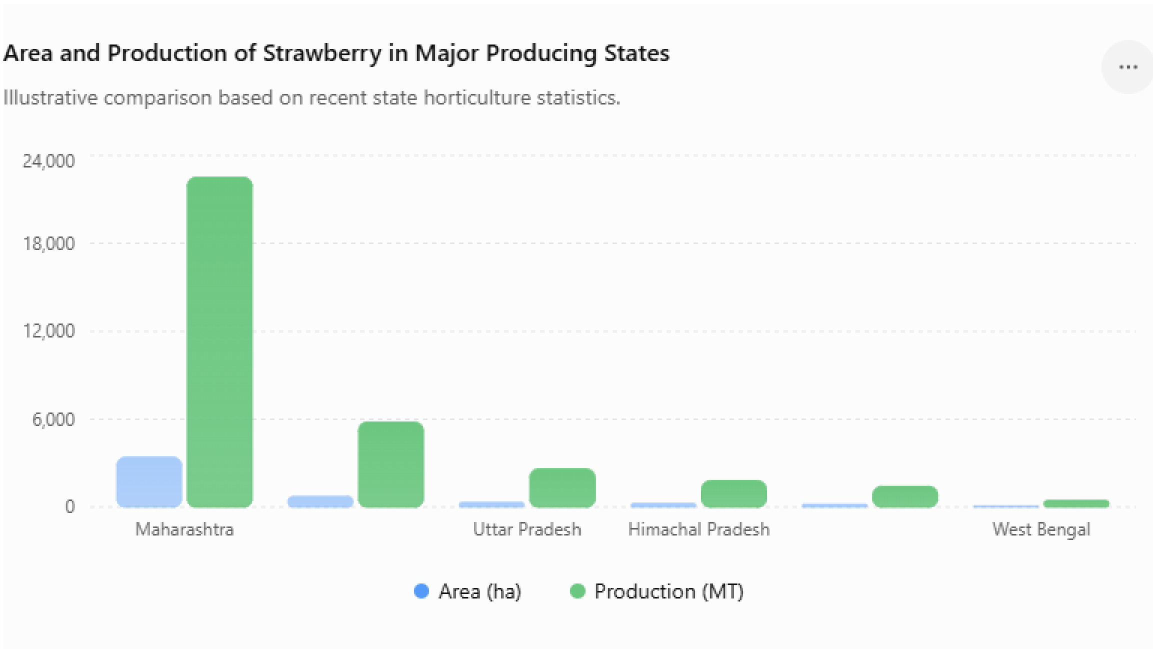
Pest and Disease Management: Integrated Pest Management (IPM), field sanitation, resistant varieties, biological control, and need-based fungicide application help control aphids, mites, powdery mildew, grey mould, and root rot.

Harvesting and Post-harvest Management: Harvest fruits at optimum maturity and maintain cold-chain storage, grading, and hygienic packaging to reduce post-harvest losses.

Prospects of Berry Cultivation in India

The future of berry cultivation in India is highly promising due to increasing health consciousness, expanding organized retail, and demand from processing industries. Government programmes under MIDH, NHB, and state horticulture missions encourage protected cultivation, drip irrigation, and post-harvest infrastructure.

Protected cultivation, precision farming, hydroponics, and climate-smart technologies enable high-quality production. Farmer Producer Organizations (FPOs), agri-startups, and food processing industries can strengthen value chains. The North Eastern Region, including Meghalaya, Sikkim, Arunachal Pradesh, Nagaland, and parts of Tripura, offers considerable potential for berry cultivation under suitable agro-climatic conditions. Challenges such as quality planting material, cold-chain infrastructure, and technical knowledge should be addressed through research, extension, and investment.



Conclusion

Berry cultivation is emerging as one of the most promising high-value horticultural enterprises in India. Scientific cultivation, improved infrastructure, supportive government policies, and strong market linkages can enhance productivity and profitability. With continued research, technological adoption, and value addition, berry cultivation can contribute significantly to sustainable agriculture, nutritional security, export earnings, and improved livelihoods.

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SUSTAINABLE FORAGE STRATEGIES FOR YEAR-ROUND DAIRY NUTRITION

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Forage constitutes the biological and economic foundation of ruminant production. However, seasonal fluctuations in forage availability driven by climatic volatility pose a significant threat to livestock productivity. In the Indian dairy, the Forage gap is the most significant structural barrier to achieving the genetic potential of both indigenous and crossbred bovines. This gap is not just a seasonal shortage it is a chronic deficiency in both the quantity of biomass and the quality of available nutrients. One of the main issues facing the global livestock business is the supply of feed as the world's population expands and the demand for animal products rises. Nonetheless, dairy and beef feed make up over 19% of the 1.29 billion tons of animal feed produced worldwide (Alltech, 2024). This percentage is much greater in some areas, especially when it comes to feeding ruminant livestock, who mostly depend on roughage and fodder. The sustainable growth of agriculture and livestock husbandry depends on the provision of adequate and superior feed (He *et al*., 2023). Ensuring year-round production requires a transition from reactive feeding to a proactive forage management strategy, integrating both high-tech cultivation and advanced preservation techniques.

Demand and Supply of Forage

India is the world's largest milk producer, yet it faces a persistent deficit in animal feed. As per IGFRI VISION 2050, there is approximately 35.6%, 10.5% and 44% deficiency of Green fodder, Dry fodder and Concentrate. The gap is exacerbated by the fact that only about 4–5% of India’s total cultivable land is under fodder production. In India, the forage gap occurs in two distinct lean periods which are Summer Gap (April–June) occurs in Post-Rabi harvest due to extreme thermic stress and water scarcity and Winter Gap (November–December) in which the transition between Kharif and Rabi crops. Traditional grazing systems often fail to meet the metabolic demands of high-yielding bovines during thermal stress or drought as the forage gap is often filled with crop residues like paddy straw or wheat straw. While this satisfies the animal's physical hunger, it leads to nutritional dilution as a result of lignification which prevent rumen microbes from accessing energy, Anti-Nutritional factors: which interfere with calcium absorption, leading to milk fever and poor bone health and producing significantly more methane per liter of milk, increasing the environmental footprint of Indian dairy.

Constraints in Fodder Production

Fodder production in India faces multiple interlinked constraints that limit sustainability and productivity. The most fundamental challenge is land scarcity, as area dedicated to fodder has stagnated at only 4–5% of cultivable land for decades (Meena *et al.*, 2018). Genetic erosion along with a low seed replacement rate (often below 20%) and limited availability of improved, climate-resilient seed varieties beyond select regions (Parihar, 2010). Water stress is another major barrier, since high-protein fodders such as lucerne and berseem demand intensive irrigation, yet much of India's fodder production remains rain-fed and vulnerable to erratic monsoons. Post-harvest inefficiencies also lead to significant wastage such as paddy straw burning, nutrient losses during sun-drying, and poor adoption of silage technology among smallholders. Additionally, most dairy farmers are smallholders who cannot afford dedicated fodder cultivation, extension services remain fragmented and the absence of organized fodder markets makes fodder cultivation a risky venture.

Strategies for Year-round Fodder Production

A. Cropping systems

- **Silvopastoral Systems:** Integration of fodder trees like *Leucaena leucocephala* (Subabul), *Moringa oleifera* (Shehjan) and *Azadirachta indica* (Neem) provide a deep-rooted nutrient source that remains green during summer lean period when ground grasses are dormant, while offering shade to mitigate heat stress. Their deep root systems can access groundwater from deeper soil strata, ensuring that the farm produces green biomass even during prolonged drought cycles.
- **Multiple cropping:** Intercropping is the strategic cultivation of two or more crop species simultaneously on the same piece of land. Intercropping had been found to increase crop yield (Li *et al.*, 2020) and resource use efficiency (Liu and Zhao, 2023). Intercropping can increase crude protein content by 11–51 % compared to monocropping (Meng *et al.*, 2022). Relay cropping is a multiple cropping system that consists in planting a second crop into a standing first crop prior to its harvest. Relay

cropping include increased crop productivity, net economic returns, land use efficiency, soil fertility, efficient nutrient cycling and pest control (Lamichhane *et al*., 2023).

- **High yielding and drought resistant varieties:** Species such as Napier grass (*Pennisetum purpureum*), Berseem (*Trifolium alexandrinum*), Lucerne (*Medicago sativa*) and Sorghum (*Sorghum bicolor*) are scientifically recognized for their exceptional biomass productivity and resilience to climatic fluctuations. These cultivars offer nutritional superiority, enhanced crude protein levels and digestibility profiles that directly optimize livestock growth and lactational output. Furthermore, the integration of specifically bred climate-resilient varieties provides a critical biological buffer against abiotic stressors, ensuring consistent forage availability during lean periods (Jain *et al*., 2021).

B. Intensive Cultivation Technologies and Precision irrigation:

- **Hydroponic Fodder Production:** Hydroponic fodder crops are produced from seeds or grains that are sprouted and grown under optimum conditions in a closed, controlled system within a short period of time. The hydroponic fodder system is a potential solution in areas where arable land is scarce and where pasture land is either limited or non-existent. Hydroponic fodders are highly digestible, palatable and fed by the animals as they are enzyme-rich feeds (Shipard, 2005). Growing cereal grains (Barley, Maize) in controlled environments produces high-quality green succulent feed in 7–10 days with 90% less water than field crops.
- **Sub-surface Drip Irrigation:** Subsurface drip irrigation technology consists of buried drip line fitted with emitters that release water directly to the plant's root zone, reducing surface evaporation and runoff (Camp, 1998) maximizes water-use efficiency and ensures consistent biomass production regardless of rainfall patterns.

C. Preservation of fodder

- **Community Fodder Banks:** Community fodder banks acts as a collective repository which facilitate resource optimization through the high-density conservation of forage during peak production cycles. They acts as a robust risk mitigation mechanism, providing a critical nutritional safety that insulates smallholder farmers from the volatility of droughts, pest outbreaks and fodder market inflations.
- **Fortification of Residues:** Crop residues and dry grasses are the major forages used for feeding livestock in India. These crop residues are low in nitrogen, minerals,

vitamins and high in fiber and lignin which restrict intake and digestibility in animals. The use of Urea Molasses Mineral Blocks (UMMB) for supplementing crop-residue-based diets for livestock has the potential to increase livestock production and net daily income. UMMB can be fed throughout the year but are more beneficially utilized during the dry season or when the animals are grazing low quality fodder.

- **Ensilage:** Silage is a preservation technology that involves anaerobic fermentation of green fodder under sealed conditions, helps maintain forage quality over extended periods (Villalobos and Serva, 2024). It is a prevailing way to preserve and supply year-round availability of moist feedstock. Silage plays a critical role in the rearing of dairy and beef cattle and it is an important source of nutrients, particularly energy and digestible fiber. Given the rising costs of feed, farmers increasingly prefer this efficient and economical source of nutrition (Akintan *et al*., 2024).

D. Utilization of Unconventional Feed Resources

- Unconventional feed sources can lessen dependency on conventional sources and diversify the fodder base. These resources include aquatic plants, tree leaves, agro-industrial byproducts, and non-traditional forages. Agro-industrial by-products including oil cakes, brans, molasses, and distiller's grains are examples of unconventional feed resources that are high in nutrients and can be added to conventional fodder. Minerals and protein are abundant in the leaves of trees including banyan, neem, and mango. To supply more feed, aquatic species such as duckweed and water hyacinth can be grown in bodies of water (Kumar et al., 2020).

Conclusion

The sustainability of India’s dairy sector depends on bridging the forage gap through a transition from reactive feeding to proactive management. To achieve nutritional perenniality, the industry must adopt climate-resilient cropping systems, such as silvopasture and high-yielding intercropping, which provide a biological buffer during lean periods. Furthermore, intensive technologies like hydroponics and subsurface drip irrigation offer high-quality succulent feed with minimal resource use. However, production must be balanced with preservation; the adoption of community fodder banks and ensilage is essential to save monsoon surpluses for summer scarcity. Ultimately, integrating these technological and social innovations will secure animal welfare and ensure a food-secure future for millions of smallholder dairy farmers.

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ONE FARMER, MANY OPPORTUNITIES: MULTI-COMMODITY FPOs ARE THE FUTURE OF NORTH EAST AGRICULTURE

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Indian agriculture is dominated by small and marginal farmers, who constitute nearly 86 percent of the country's farming community. Their small landholdings, limited bargaining power, inadequate access to quality inputs, institutional credit, modern technologies, and organized markets have long constrained agricultural profitability. To address these challenges, the Government of India has promoted the formation of Farmer Producer Organizations (FPOs) as farmer-owned business enterprises that aggregate production, reduce transaction costs, strengthen market linkages, and improve farm incomes. Under the Central Sector Scheme for Formation and Promotion of 10,000 FPOs, thousands of producer organizations are being established across the country to transform agriculture into a more competitive and market-oriented enterprise.

Although the FPO model has demonstrated considerable success in many parts of India, its implementation in the North Eastern Region (NER) presents unique opportunities as well as challenges. The region comprises eight states characterized by hilly terrain, fragmented landholdings, diverse agro-climatic conditions, rich biodiversity, tribal farming systems, and highly diversified agricultural production. Unlike the extensive monocropping systems prevalent in several states of northern and western India, farmers in Tripura, Assam, Meghalaya, Mizoram, Nagaland, Arunachal Pradesh, Manipur, and Sikkim generally cultivate multiple crops and integrate livestock, fisheries, horticulture, spices, bamboo, and forest-based enterprises within the same farming system. Consequently, the traditional single-commodity FPO model often struggles to achieve economies of scale and year-round business operations in this region, whereas multi-commodity FPOs offer greater economic resilience, diversified income opportunities, and long-term sustainability. Research on agricultural diversification in Tripura has similarly shown that diversified farming systems significantly enhance farm income and reduce production risk.

Understanding Single-Commodity and Multi-Commodity FPOs

A single-commodity FPO primarily focuses on one agricultural product such as rice, pineapple, ginger, tea, rubber, coffee, fish, or turmeric. All business activities, including procurement, grading, processing, storage, and marketing, revolve around that specific commodity. Such organizations are effective where production volumes are sufficiently high, markets remain stable, and farmers specialize in a single crop.

In contrast, a multi-commodity FPO deals with several agricultural and allied products simultaneously. It may aggregate fruits, vegetables, spices, pulses, bamboo products, honey, fish, livestock products, mushrooms, medicinal plants, and processed foods under one institutional framework. This diversified business model enables the organization to remain operational throughout the year while serving a broader farmer base.

Agricultural Characteristics of North Eastern India

The North Eastern Region possesses exceptional ecological diversity. Annual rainfall exceeds 2,000 mm in many locations, temperatures remain favourable for year-round cultivation, and farmers grow an impressive range of crops including rice, maize, millets, ginger, turmeric, black pepper, pineapple, orange, banana, jackfruit, vegetables, arecanut, bamboo, medicinal plants, and numerous indigenous horticultural crops.

Tripura represents a typical example of this diversified production system. Most farm families cultivate seasonal vegetables during winter, paddy during monsoon, fruits and spices on uplands, maintain backyard poultry and pigs, rear cattle or goats, harvest bamboo and non-timber forest products, and frequently practice integrated fish farming. Such diversified production creates continuous marketable surplus throughout the year but in relatively small quantities for each commodity. Review studies on agricultural value chains in the North-East conclude that strengthening value addition, processing, aggregation, and market integration across multiple products is essential for improving farmers' incomes.

Why Single-Commodity FPOs Face Challenges in North East India

The single-commodity approach has several limitations in the North Eastern context.

Limited production volume remains one of the biggest constraints. Since most farmers own less than one hectare of land and cultivate several crops simultaneously, individual production of any single commodity is relatively low. Aggregating sufficient volume for bulk marketing becomes difficult.

Seasonality of production further restricts business operations. Many crops such as pineapple, ginger, turmeric, and oranges have specific harvesting seasons. Consequently, FPOs dependent on a single commodity often remain inactive for several months every year.

Price volatility exposes farmers to significant financial risks. Market prices of agricultural commodities fluctuate widely depending on weather, production, transportation costs, and market demand. When an FPO depends solely on one commodity, declining prices directly affect its revenue and sustainability.

Climate vulnerability is another major concern. The North Eastern Region experiences frequent floods, landslides, cyclones, drought-like conditions, and pest outbreaks. Crop failure in one commodity may severely weaken the financial health of a specialized FPO.

Why Multi-Commodity FPOs are More Feasible

1. Better Utilization of Resources

A multi-commodity FPO can utilize warehouses, grading facilities, transport vehicles, pack houses, processing equipment, and human resources throughout the year instead of during only one harvesting season. This improves operational efficiency and reduces overhead costs.

2. Continuous Business Throughout the Year

Different crops mature in different seasons. Vegetables may be marketed during winter, pineapple during summer, spices after harvest, mushrooms throughout the year, while fisheries and livestock provide continuous income. This creates uninterrupted business opportunities.

3. Reduced Business Risk

Diversification spreads financial risk. Even if market prices decline for ginger, income from vegetables, fish, poultry, bamboo products, honey, or processed foods can compensate for losses.

4. Higher Membership Base

Farmers producing different commodities can become members of the same organization, increasing shareholder participation, equity mobilization, and business turnover. A larger membership also strengthens institutional bargaining power.

5. Better Market Negotiation

Buyers increasingly prefer suppliers capable of delivering multiple products consistently. Hotels, supermarkets, food processors, exporters, and institutional buyers often seek integrated procurement rather than dealing separately with numerous organizations.

6. Greater Value Addition Opportunities

Processing several commodities allows FPOs to establish diversified enterprises such as spice grinding, fruit processing, bamboo handicrafts, honey packaging, mushroom dehydration, fish processing, and millet-based products. Value addition substantially enhances profitability while creating rural employment.

7. Improved Access to Finance

Financial institutions generally prefer organizations with diversified income sources because business risks are comparatively lower. Multi-commodity enterprises often demonstrate stronger cash flow and improved loan repayment capacity.

Scientific Evidence from Tripura and North Eastern India

Recent studies increasingly support diversified producer organizations in the North East.

A case study of Bagma Agri Producer Company Limited in Tripura demonstrated that its diversified portfolio—including dairy, fisheries, horticulture, and apiculture—enhanced organizational adaptability, institutional partnerships, and long-term sustainability despite existing marketing constraints. The study concluded that diversified business activities strengthened resilience against market uncertainties.

Another study evaluating the performance of FPOs in Tripura found that organizational performance depended significantly on managerial competence, member participation, financial strength, and operational effectiveness. FPOs possessing stronger institutional capacity and diversified activities generally performed better than organizations with limited business portfolios. Research on FPO members in Tripura further observed that although awareness regarding FPO functioning is moderate, strengthening member capacity, business diversification, and institutional support can substantially improve organizational performance and farmer participation.

Studies on agricultural diversification in Tripura have also established that diversified farming systems significantly increase farm income, improve livelihood security, and reduce production risks, thereby reinforcing the rationale for multi-commodity producer organizations.

Opportunities for Multi-Commodity FPOs in Tripura

Tripura possesses enormous potential for integrated producer organizations due to its diverse agricultural resources. A single FPO may simultaneously aggregate:

- Pineapple and other fruits
- Ginger, turmeric and black pepper
- Seasonal vegetables
- Rice and pulses
- Fish and duck farming products
- Piggery and poultry
- Bamboo products
- Agarwood products
- Honey and mushrooms
- Non-timber forest products
- Organic and natural farming products

Such diversification enables continuous business, better utilization of infrastructure, stronger bargaining power, and greater opportunities for branding under regional identities such as "Organic Tripura" or "Products of North East India."

Policy Recommendations

To promote sustainable FPO development in the North Eastern Region, policymakers should encourage diversified business planning rather than restricting organizations to a single commodity. Financial assistance should prioritize common infrastructure such as integrated pack houses, cold storage, processing centres, primary collection hubs, refrigerated transportation, digital marketing platforms, and branding facilities.

Capacity-building programmes should train FPO directors and CEOs in diversified enterprise management, business planning, financial management, quality assurance, and digital marketing. Convergence among ICAR, KVKs, NABARD, SFAC, State Agriculture Departments, Rural Livelihood Missions, and research institutions will further strengthen the ecosystem required for successful multi-commodity enterprises.

Conclusion

Farmer Producer Organizations have emerged as one of the most promising institutional innovations for transforming Indian agriculture. However, organizational models must reflect regional realities rather than adopting a uniform national approach. The North Eastern Region, particularly Tripura, is characterized by small landholdings, diversified farming systems, rich biodiversity, and seasonal production of numerous agricultural commodities. Under such conditions, multi-commodity FPOs provide greater operational flexibility, continuous business opportunities, diversified income streams, reduced financial risk, stronger market linkages, and improved organizational sustainability than single-commodity organizations.

Future FPO promotion strategies in North Eastern India should therefore adopt integrated, market-oriented, and value chain-based business models that combine agriculture, horticulture, livestock, fisheries, bamboo, non-timber forest products, and value-added processing. Such diversified producer enterprises will not only strengthen farmers' incomes but also contribute significantly to rural employment, entrepreneurship, food security, and sustainable agricultural development across the region.

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HIDDEN PLASTICS IN URBAN COMPOST: SOURCES, RISKS AND SUSTAINABLE MANAGEMENT

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Composting converts food scraps, vegetable residues and garden waste into a useful soil amendment. It reduces pressure on landfills, recycles nutrients and adds organic matter to soil, making it an important link between urban waste management and sustainable agriculture. Yet apparently clean compost may carry an almost invisible contaminant: microplastics. Plastic bags, food wrappers, disposable items, synthetic fibres and small labels enter the organic waste stream when segregation is poor. Large pieces may be removed during sorting, but fine films, fibres and fragments often remain. Compost can therefore return nutrients to soil while also carrying persistent plastic particles from cities to farms.

This concern does not justify abandoning composting. It calls for cleaner feedstock, better processing and stronger quality control so that the final product remains both agronomically useful and environmentally safe.

Understanding Microplastics and Their Sources

Microplastics are plastic particles smaller than 5 mm and occur as fragments, films, fibres, beads or foam. Primary microplastics are manufactured at a small size, whereas secondary microplastics form when larger products break down through heat, sunlight, abrasion and weathering. Most particles in municipal compost are secondary microplastics derived from ordinary consumer plastics.

Contamination usually begins before waste reaches the plant. Kitchen residues are often discarded in plastic bags or mixed with packaging, disposable cups and cutlery, coated paper, produce stickers, synthetic tea bags, wet wipes and textile fibres. Once these materials become mixed with moist organic waste, complete separation is difficult. Feedstock quality strongly determines compost quality. Separately collected kitchen, market and garden waste generally contains fewer plastics than mixed municipal waste. Films can resemble dried leaves, fibres become entangled with organic matter and tiny fragments pass through screens. “Biodegradable” or “compostable” plastics may also remain partly degraded when a facility does not provide the required temperature, moisture and treatment time.

Common polymers include polyethylene, polypropylene, polyethylene terephthalate, polystyrene and polyvinyl chloride. Their density, flexibility and resistance to weathering differ, which influences where they occur in compost and how easily they can be separated. Light films may remain near the surface, dense fragments may mix with mineral matter, and fibres can become embedded in partially decomposed residues.

Table 1. Major sources and forms of plastic contamination in municipal compost

Source	Likely form	Why it persists
Carry bags and packaging	Films and fragments	Tear during handling; fine pieces pass through screens.
Disposable food-service items	Rigid fragments and foam	Small items are difficult to separate from wet waste.
Textiles, wipes and cleaning materials	Synthetic fibres	Fibres entangle with organic matter and escape sieving.
Labels, stickers and coated paper	Small films and adhesive pieces	Their size and close contact with food hinder removal.
Compostable plastics	Partly degraded films	Breakdown remains incomplete under unsuitable conditions.

Fate of Plastics During Composting

Microorganisms convert degradable organic matter into carbon dioxide, water and stable humus-like material, but conventional plastics do not follow the same pathway. They may become brittle, cracked or discoloured without being completely mineralised.

Shredding, mixing, turning and screening can tear bags and wrappers into progressively smaller pieces. Heat, moisture and friction accelerate surface weathering, making particles harder to detect and recover. Plastic may also become relatively concentrated because organic mass declines during decomposition while most plastic remains. Ageing particles can release additives such as plasticisers, pigments and stabilisers, or bind other pollutants on their surfaces. Thus, disappearance from sight is not proof of biodegradation; composting may change the size and condition of plastics without eliminating them.

Why Microplastic-Contaminated Compost Matters

Compost is commonly applied repeatedly, so even modest contamination in each batch can create a cumulative input. Field evidence shows that a microplastic signal may remain in soil years after application stops. Once particles are dispersed through the plough layer, their removal is practically impossible.Films, fibres and fragments can alter soil aggregation, pore arrangement, bulk density, aeration, water retention and infiltration. The response varies with polymer type, particle shape, size, concentration and soil properties. Some experiments report adverse effects, others limited change, and a few temporary improvements in specific properties. The main concern is therefore not uniform or immediate damage, but persistent inputs that can modify soil processes in unpredictable ways.

Earthworms, nematodes and springtails may ingest particles or experience altered habitats. Because these organisms support decomposition, aggregation and nutrient redistribution, changes in their activity can affect soil functioning. Plastic surfaces also develop microbial biofilms, sometimes called the plastisphere, and may influence microbial communities and enzymes involved in carbon, nitrogen and phosphorus cycling.

Plants are affected mainly through changes in the root environment. Altered soil structure, moisture, nutrient availability and microbial activity may influence germination, root growth, photosynthesis and biomass. Very small particles can interact closely with roots, although crop uptake under realistic field conditions and its implications for food safety remain uncertain. This uncertainty makes prevention preferable to waiting for every long-term effect to be quantified.

Particles introduced with compost may not remain where they are applied. Wind erosion, surface runoff, drainage, soil movement and the activity of soil organisms can redistribute them vertically and horizontally. This creates a pathway from compost-amended fields to neighbouring land and water bodies.

Table 2. Potential effects in compost-amended soils

Component	Possible response	Scientific qualification
Soil structure	Changes in aggregation, pores and bulk density	Effects depend on polymer, shape, dose and soil type.
Water and air	Modified infiltration, retention and aeration	Films, fibres and fragments behave differently.
Soil fauna	Altered feeding, movement or reproduction	Much evidence comes from controlled experiments.

Microorganisms	Changes in biofilms, communities and enzymes	Responses may be positive, negative or negligible.
Crops	Effects on roots, photosynthesis and biomass	Field-scale and food-chain effects remain uncertain.
Co-contaminants	Additive release or pollutant sorption	Ageing and polymer chemistry influence interactions.

Detection and Quality Assessment

Microplastics are difficult to measure in compost because plant fibres, humus and mineral particles may resemble plastic. Representative samples must be collected from several locations within a batch, dried and sieved. Organic matter is removed by controlled digestion, and density separation is used to recover lighter particles. Suspected particles are then classified under a microscope. Visual identification alone is unreliable, so polymer identity is commonly confirmed by Fourier-transform infrared or Raman spectroscopy. Pyrolysis coupled with gas chromatography–mass spectrometry can estimate polymer mass even when individual particles are difficult to count.

Comparison among studies remains challenging because methods differ in sampling, minimum particle size, extraction solution, identification and reporting units. Traditional standards mainly regulate visible impurities, yet visually clean compost may still contain small particles. Quality systems should therefore combine feedstock traceability, limits for visible contaminants and progressively standardised microplastic monitoring. Monitoring should report both particle abundance and plastic mass, together with the size range examined. Without these details, a compost containing many tiny fibres may appear less contaminated than one containing a few heavier fragments, depending on the reporting method.

Management from Waste Generation to Farm Application

The most effective strategy is to prevent plastics from entering organic waste. Removing microscopic particles from finished compost is technically difficult and costly. Households, markets, hotels and institutions should separate food and garden waste without conventional plastic liners. Municipal collection must preserve this separation during transport; remixing segregated waste immediately undermines feedstock quality and public participation.

At compost plants, contaminants should be removed before shredding. Manual sorting, trommel screens, air classifiers, ballistic separators and optical systems target different materials, and staged separation is more effective than relying on final screening alone.

Decentralised processing of clean household, market and garden waste can further reduce handling and cross-contamination.

Producers should document feedstock origin, processing conditions, maturity, nutrient content and physical impurities. Independent testing and certification would help farmers distinguish reliable products from contaminated compost. Farmers should inspect compost for visible films and fibres, buy from traceable sources and avoid repeated application of poor-quality batches. Packaging producers and retailers must also reduce unnecessary materials, improve recyclability and support collection under extended producer responsibility. Management is a chain. Failure during segregation, transport, preprocessing, screening, certification or field use simply transfers the plastic burden to the next stage.

Municipal authorities should combine awareness with routine inspection, incentives for correct segregation and penalties for repeated mixing. Extended producer responsibility can further reduce difficult-to-recycle packaging entering municipal waste.

Table 3. Priority controls along the composting chain

Stage	Priority action	Expected benefit
Waste generation	Separate organic waste from plastics	Prevents contamination at source.
Collection	Keep streams separate during transport	Preserves feedstock quality.
Preprocessing	Remove plastics before shredding	Avoids fragmentation into smaller particles.
Composting	Use staged sorting and screening	Reduces films, fibres and rigid pieces.
Product quality	Test, certify and label compost	Supports informed purchasing.
Farm use	Inspect products and reject contaminated batches	Limits cumulative loading in soil.

The Way Forward

Municipal composting should remain part of sustainable waste and soil management, but success must be judged by product quality rather than only by the quantity of waste processed. Clean feedstock is the foundation; technology cannot fully compensate for mixed waste containing thin films, fibres and multilayer packaging. Progress requires practical, affordable and standardised methods for measuring microplastics, followed by enforceable quality limits. Long-term field studies should assess repeated applications across different soils, crops and climates. Research must also distinguish conventional, bio-based and certified compostable polymers because “biodegradable” does not guarantee complete breakdown in every facility.

The direction is already clear: segregate organic waste at source, maintain separation during collection, remove plastics before size reduction, certify finished compost and create market demand for clean products.

Conclusion

Municipal compost can recycle nutrients and improve soil organic matter, but contaminated feedstock can turn it into a pathway for microplastics. Mixed waste becomes still harder to clean after shredding and composting convert visible plastics into small fragments and fibres.

The answer is not to reject composting, but to produce better compost through source segregation, separate collection, early plastic removal, standardised testing and transparent certification. Shared responsibility can allow organic waste to return safely to soil without carrying the city’s plastic pollution with it.

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POSTBIOTICS: THE NEXT GENERATION OF HEALTH PROMOTERS IN AQUACULTURE

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Aquaculture plays a crucial role in global food security by providing high-quality animal protein and supporting the livelihoods of millions of people. However, disease outbreaks continue to be one of the major constraints to sustainable aquaculture production. Traditionally, antibiotics have been used to control bacterial diseases in fish and shrimp farming. Excessive and indiscriminate use of antibiotics has led to concerns about antimicrobial resistance, environmental contamination, and food safety.

In recent years, researchers have focused on developing sustainable alternatives to antibiotics. Among these innovations, postbiotics have emerged as a promising strategy for improving aquatic animal health. Postbiotics offer many of the benefits associated with probiotics while overcoming some of their limitations, making them an attractive option for modern aquaculture.

What Are Postbiotics?

Postbiotics are preparations of non-living microorganisms and their bioactive metabolites that provide health benefits to the host. They are produced during the fermentation process of beneficial bacteria and may contain organic acids, bacteriocins, enzymes, peptides, exopolysaccharides, vitamins, and microbial cell components.

Unlike probiotics, postbiotics do not contain live microorganisms. Therefore, they are more stable during feed processing, storage, and transportation while still retaining their biological activity.

Importance of Postbiotics in Aquatic Animal Health

Enhancing Disease Resistance

Disease outbreaks caused by bacterial pathogens such as *Vibrio*, *Aeromonas*, and *Photobacterium* species result in significant economic losses in aquaculture. Postbiotics contain antimicrobial compounds that inhibit the growth of harmful bacteria and reduce pathogen colonization in the digestive tract.

Several studies have demonstrated that postbiotic supplementation can improve survival rates in fish and shrimp challenged with bacterial pathogens.

Strengthening Immune Responses

The immune system serves as the first line of defense against infectious diseases. Postbiotics stimulate innate immune responses by increasing phagocytic activity, lysozyme production, antioxidant enzyme activity, and the expression of immune-related genes.

Enhanced immunity enables aquatic animals to better resist infections and recover more rapidly from environmental stressors.

Improving Gut Health

The gastrointestinal tract is essential for digestion, nutrient absorption, and disease resistance. Postbiotics help maintain intestinal integrity and support the growth of beneficial microbial communities. A healthy gut environment improves feed utilization and overall animal performance.

Promoting Growth Performance

Healthy fish and shrimp exhibit better growth rates and feed conversion efficiency. By improving nutrient digestion and absorption, postbiotics contribute to increased weight gain and productivity. Several feeding trials have reported improved growth performance in aquaculture species receiving postbiotic-supplemented diets.

Mitigating Environmental Stress

Aquatic animals are frequently exposed to stress caused by temperature fluctuations, salinity changes, handling, transportation, and poor water quality. Postbiotics possess antioxidant properties that help reduce oxidative stress and improve the resilience of fish and shrimp under challenging environmental conditions.

Advantages

- High stability during feed manufacturing.
- Longer shelf life compared to live probiotics.
- No risk of introducing live microorganisms into culture systems.
- Easier storage and transportation.
- Reduced concerns regarding the transfer of antimicrobial resistance genes.
- Consistent efficacy under varying environmental conditions.

Applications in Aquaculture

Postbiotics can be incorporated into:

- Fish and shrimp feeds
- Hatchery production systems
- Biofloc technology systems
- Recirculating aquaculture systems (RAS)
- Functional aquafeeds

Their use has been associated with improved survival, enhanced immunity, better feed conversion ratios, and reduced disease incidence in several cultured species.

Future Prospects

The growing demand for sustainable aquaculture practices is expected to drive increased adoption of postbiotic technologies. Advances in microbiology, biotechnology, and feed science are facilitating the development of species-specific postbiotic products with enhanced efficacy.

Future research is likely to focus on identifying novel microbial metabolites, understanding mechanisms of action, and optimizing application methods for different aquaculture systems.

Conclusion

Postbiotics represent an innovative and sustainable approach to aquatic animal health management. Their ability to enhance immunity, improve gut health, promote growth, and reduce disease susceptibility makes them a promising alternative to antibiotics. As aquaculture moves toward environmentally responsible production practices, postbiotics are expected to play an increasingly important role in ensuring healthy fish and shrimp production while supporting the long-term sustainability of the industry.

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