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Indigenous and aromatic rice production strategies in a crop-diversified approach under natural and organic farming systems: A review

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Abstract
In the current era of climate change, soil degradation, and increased consumer awareness of food quality, there is renewed scientific and policy interest in restoring these historic cultivars through environmentally sound agricultural practices. With a focus on natural farming (as supported by Zero Budget Natural Farming and Fukuoka-inspired approaches) and certified organic systems, this paper explores the existing methods for growing native and aromatic rice within cropdiversified frameworks. Value chain integration, integrated nutrient cycling, soil biological management, pest and disease control through ecological variety, and seed conservation and selection are important topics. The study also identifies options to move forward through agroecological research, farmer participatory breeding, and premium market linkages, while highlighting issues with poor yields, marketability, and policy shortages. The assessment also emphasises how crop diversification can improve productivity, climate resilience, nutrient cycling, and farm profitability through the use of rice-based rotations, legumes, oilseeds, fodder crops, rice–fish systems, and the System of Rice Intensification (SRI). Sustainable methods for managing soil, water, weeds, and nutrients are given particular attention, along with value-chain development, organic certification, and market prospects for premium native rice.

Keywords: Aromatic rice, crop diversification, natural farming, organic farming, production strategies

Introduction

Rice (*Oryza sativa* L.) is a staple food for over half of the world's population and is important to the agricultural economics of tropical and subtropical nations. Among the thousands of known rice varieties that are valued for their flavour, aroma, cooking quality, and nutraceutical benefits include Gobindobhog, Tulaipanji, Kalonunia, Joha, Badshah Bhog, Radhunipagal, Basmati, and several landraces of the northeastern Indian subcontinent. These ancient cultivars, which are a part of complex, biodiverse cropping systems, have been kept for many generations by smallholder and subsistence farmers. The aromatic rice showed morphological differences in terms of panicle metrics such as length, weight, test weight, number of panicles, grains/panicle, and chaffs/panicle. For future rice breeding efforts, certain fragrant rice varieties, including Radhatilak, Kalonunia, and Sitabhog are favoured because of their longer panicles, larger grains per panicle, and higher panicle weight (Patra, 2025a). According to Patra *et al*. (2025c) and Roy *et al*. (2025) [13, 78], traditional paddy varieties, such fragrant ones, have a large nutritional and medicinal value, can survive tremendous stress, and also improve socioeconomic qualities. The traits of these paddy cultivars may be utilised in the future to choose the parents in a breeding attempt to produce hybrid varieties with superior yields (Patra, 2023a) [16]. To reduce the use of chemical pesticides, many studies have documented the use of less toxic and organic seed treatments to improve seed quality and field performance (Mandal *et al*., 2011a; 2011b; Patra *et al*., 2012; Patra., 2013; 2016b; 2017a & 2017b; Patra & Burman, 2017 [64, 65, 66, 69, 80]; Patra, 2023b). In this regard, it has been stated that farmers should be especially aware of the reaction of temperature, relative humidity, excessive draught, soil salinity, soil temperature, and soil pH to apply better management techniques and obtain high-quality seed (Patra., 2023c; 2025b; 2025c; 2025e) (Patra, 2022) [63, 78, 128].

In addition to significantly raising yields of contemporary high-yielding varieties (HYVs), the Green Revolution of the 1960s and 1970s led to the displacement of many native cultivars, homogenisation of rice landscapes, and reliance on chemical inputs (Rahaman *et al*., 2022) [88]. This change resulted to a decrease in agrobiodiversity, a fall in soil health, and a loss of traditional agricultural wisdom. Today, however, conventional rice varieties and the agricultural practices that sustain them are being reevaluated due to mounting evidence of the environmental implications of intense rice monocultures, such as greenhouse gas emissions, groundwater depletion, and pesticide contamination. By integrating pulses and oilseeds, rice fallow utilisation leads crop area utilisation (Hedayetullah *et al*., 2018; Rahaman *et al*., 2022) [1, 88].

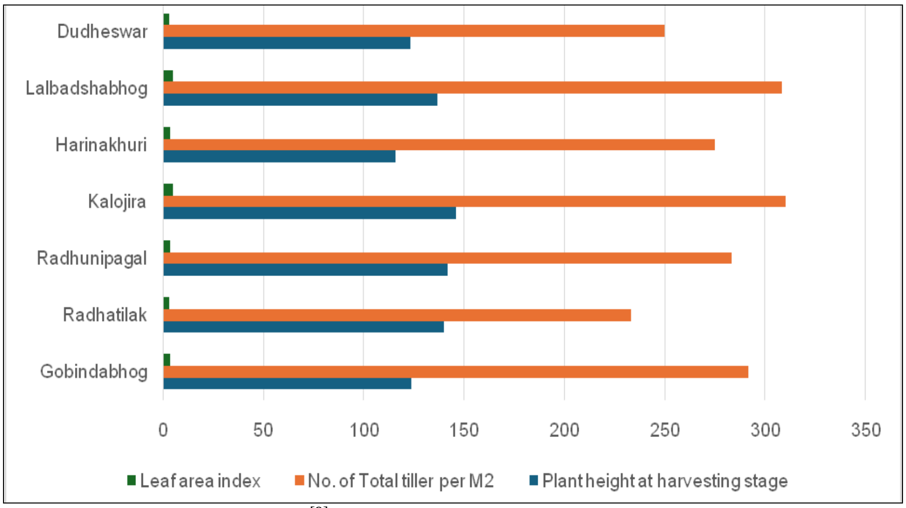
By utilising ecological processes, lowering external inputs, and boosting soil biological activity, natural and organic farming systems provide an appealing framework for growing native and fragrant rice. These systems' integrated crop diversification enhances household nutrition and farm resilience while providing additional protection against pest and climate hazards. The present understanding of production tactics, difficulties, and prospects in this field is summarised in this review (Singh *et al*., 2014, 2014a, 2014b, 2025) [44, 93].

Source: P.N. Bhaduri Crop Research and Seed Multiplication Farm, The University of Burdwan

Fig 1: Some important Indigenous and aromatic rice cultivars

Diversity and the BriefImportance of Indigenous and Aromatic Rice

A subset of cultivars known as aromatic cultivars are identified by the presence of 2-acetyl-1pyrroline (2-AP), which is the main scent chemical produced by the BADH2 gene. Geographical Indication (GI)-tagged products of great cultural and economic significance include Tulaipanji from North Bengal, Joha rice from Assam, and Gobindobhog from West Bengal.In contrast to contemporary HYVs and hybrid rice in rice fallow conditions, these traditional varieties frequently have better nutritional profiles—higher levels of anthocyanins in pigmented types, resistant starch, zinc, and iron—beyond aroma and taste (Hedayetullah and Dolai, 2019; Giri *et al*., 2023; Hedayetullah, 2023) [6, 12].Additionally, they typically have stronger allelopathic qualities that naturally control weeds, deeper root systems that are adapted to rain-fed and low-input conditions, and greater tolerance for drought, submersion, or salinity in their native settings. These characteristics fit in nicely with the ideas of natural and organic farming, which rely on crop protection from varietal characteristics rather than external chemicals. Figure 2 displays the growth performance of aromatic rice cultivated in the New Alluvial Zone utilising an organic production system during the kharif season of 2022 [15]. The growth parameters depicted in the image illustrate how crop development is impacted by organic nutrient management. Plant height, tiller count, leaf area, dry matter buildup, and crop growth rate (if applicable) are some of these traits. In addition to improving the physical and biological properties of the soil, increasing microbial activity, and promoting delayed nutrient release, organic farming practices lead to healthy vegetative development and greater plant vigour.

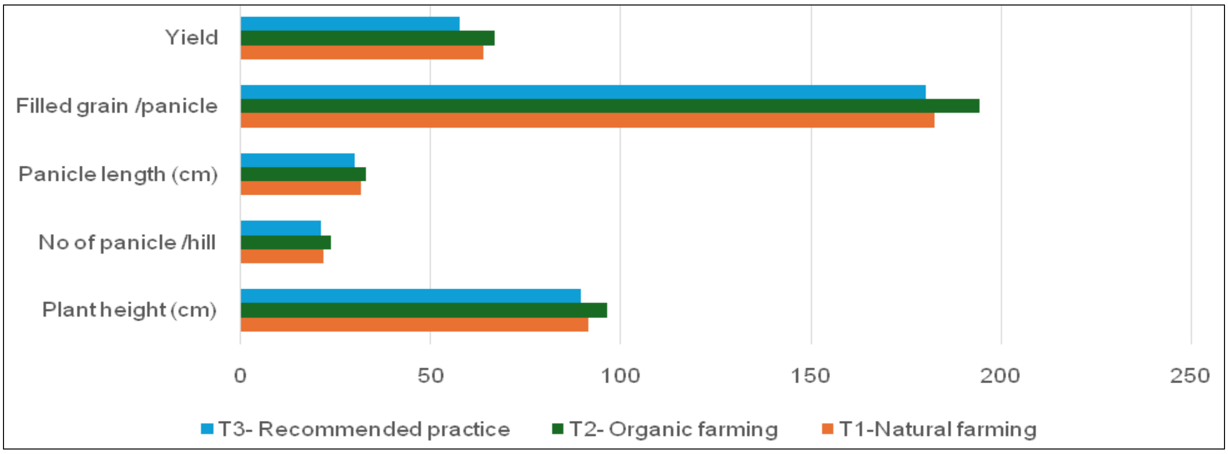


Source: Mohapatra *et al*., 2024 [9]

Fig 2: Aromatic rice growth metrics in the new alluvial zone under organic management during the 2022 kharif season

Organic and Natural Farming Systems for the Production of Rice

Considered an agroecological strategy, Natural Farming (NF) is a unique chemical-free farming method (Rosset *et al*., 2012) [126]. It is thought that Masanobu Fukuoka, a Japanese farmer, invented agro-ecological practices. In the mid-1990s, Sh. Subash Palekar, an Indian farmer, launched the locally modified version of these practices in India under the name "Zero Budget Natural Farming (ZBNF)."The use of Jeevamritha and Beejamritha is the foundation of Natural Farming techniques. When applied to the field or foliage, Jeevamritha—a liquid fermented mixture of cow dung, cow urine, jaggery, pulses, flour, and bund soil—contains a multitude of beneficial microbes that function as a bio-stimulant, boosting the activity of soil microorganisms as well as phyllospheric microorganisms. Additionally, Beejamritha is Jeevamritha without the water used to cure seeds. In order to support the plants' healthy growth, beneficial bacteria are anticipated to colonise the roots and leaves of germinating seeds. Achhadana (bio-mulching), intercropping, and the adoption of indigenous seeds are further key components. These inputs are made from locally available resources, primarily desi cow dung and pee, and are meant to increase the native soil microbiome rather than feeding the plant externally (Zaman and Hedayetullah, 2025c, 2025d, 2025e, 2025f) [29]. ZBNF-based rice cultivation can significantly reduce input costs while producing yields that are either acceptable or comparable to those of traditional types, according to research from Karnataka and Andhra Pradesh. Figure 3 compares the grain yield and important yield-related traits of rice cultivated with natural, organic, and recommended crop management practices. The yield-attributing indicators that demonstrate how different crop management and fertiliser techniques impact rice productivity include the number of productive tillers per hill, panicle length, number of filled grains per panicle, test weight, and grain yield (if applicable). The recommended approach, which entails scientifically balanced nutrient and crop management, usually yields the highest yield because there is enough nutrient availability throughout the crop growth period. Even though organic management often leads to somewhat lower yields during the transition phase, it enhances soil fertility, microbial activity, and longterm sustainability. Natural farming practices promote ecological balance by lowering external inputs and improving soil biological health; however, yields may vary depending on local agroclimatic conditions and management efficacy. Overall, the picture shows how productivity and sustainability are traded off, emphasising how integrated and environmentally friendly production methods may produce reliable rice harvests while promoting soil health and environmental preservation. Organic farming (T2) comes out ahead on every metric, while the recommended practice (T3) trails slightly behind natural farming (T1) on most measures except being close on panicle length (Fig 3).



Source: Annual report, year 2023-24, AICRP on Chickpea, Directorate of Research, BCKV, Mohanpur, Nadia, West Bengal

Fig 3: Yield and Yield attributing characters of rice under natural, organic and recommended practices

According to Hedayetullah *et al*. (2026) [14], organic farming had the lowest yield (1349 kg/ha), whereas recommended practice (1620 kg/ha) outperformed natural farming (1564 kg/ha). The statistical significance of these differences is confirmed by the CD at 5% (97.11). The "NS" (nonsignificant) CD value indicates that there is no discernible difference between the three treatments, which were all almost identical (4250–4325 kg/ha). Compared to organic farming (30.2%), recommended practice (34.5%) and natural farming (33.7%) fared similarly and significantly better; that is, organic plots produced similar biomass but converted less of it into grain.

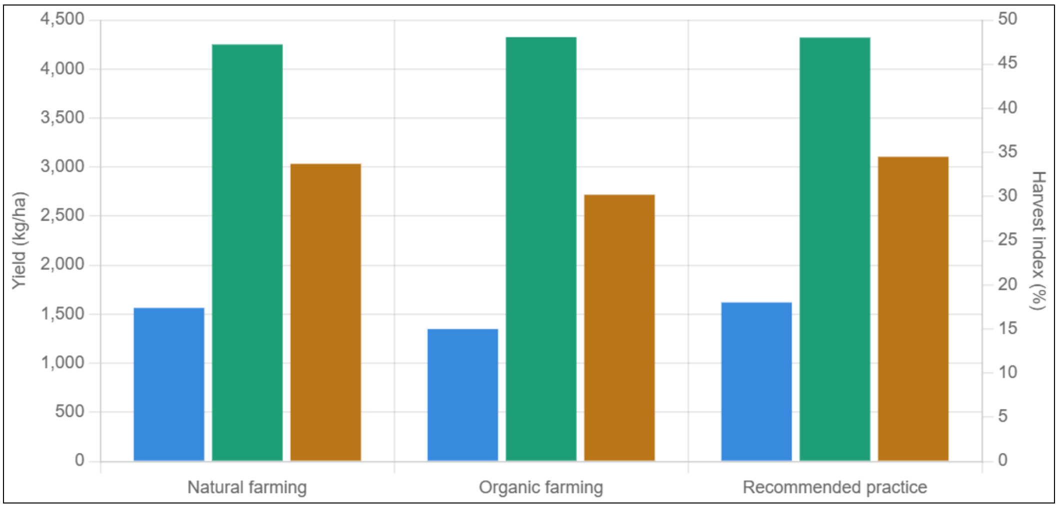
A wider range of approved inputs, such as compost, vermicompost, biofertilizers (Azospirillum, Rhizobium, PSB), botanical pesticides (neem, pyrethrin), and permitted minerals, are permitted in certified organic rice production, which is governed by international standards (IFOAM) and national standards (e.g., NPOP in India, USDA Organic in the United States, EU Organic Regulation). India currently produces more than 700,000 hectares of organic rice, with notable concentrations in Uttarakhand, Sikkim, Madhya Pradesh, and Northeast India, where traditional variety farming has mostly persisted (Zaman and Hedayetullah, 2020, 2020a, 2022, 2025, 2025a, 2025b) [29, 99, 101].

Techniques for Crop Diversification in Rice-Based Cropping Systems

In the context of native rice farming, crop diversification includes temporal, geographical, and functional aspects when rice is left fallow (Hedayetullah, 2022; Hedayetullah and Sadhukhan, 2018) [88, 90]. To break the cycles of pests and diseases, fix atmospheric nitrogen, and improve soil organic matter, rice can be temporarily alternated with vegetables, oilseeds, or legumes (green gram, lentil, and black gram) in the post-kharif season (Hedayetullah, *et al.*, 2025) [29]. In flooded fields, intercropping rice with azolla, an aquatic fern that fixes nitrogen, has been shown to provide 20–40 kg N/ha while controlling weeds through surface coverage and producing green manure. In addition to facilitating the early sowing of rabi crops and reducing salinity buildup in the soil of various land situations, particularly medium land and highland/ridges/dikes in land shaped area, raising land and constructing water harvesting structures decreased the problem of drainage congestion during the kharif season. Additionally, the fertility status and biological activities in the soil were increased under land shaping techniques (Burman *et al.*, 2015) [5].

Traditionally practised in Bengal, Assam, and Southeast Asia, rice-fish farming systems are a prime example of functional diversification: fish control weeds and insect larvae, recycle nutrients through excreta, and give farmers extra money and household protein. It has been discovered that the land shaping models—farm pond, paddy-cum-fish, deep-furrow & high ridge, and broad bed & furrow system—have produced land that is suited for raising fish and growing a variety of crops. According to financial analysis of these land shaping models, investing in such interventions is both financially feasible (IRR, 36-48%; NPV, 0.97-3.67 lakhs; BCR, 1.20-1.58; and payback period, 1.41-2.13 years) and appealing for the coastal regions of the Andaman & Nicobar Islands and Sundarbans (Mandal *et al.*, 2015) [58].

According to Zaman and Hedayetullah (2025g) [29], the System of Rice Intensification (SRI), which is widely used for both HYVs and conventional varieties, offers principles that are compatible with both organic and natural systems. These principles include transplanting young seedlings singly, widening spacing, intermittent irrigation, and active soil aeration through mechanical weeding. SRI has demonstrated yield gains of 15–30% above traditional puddled transplanting when applied to aromatic traditional varieties under organic input regimes, while using 25–40% less irrigation water—a major benefit in climate-stressed circumstances. Figure 4 demonstrated how both organic and natural farming systems provide sustainable options by preserving soil quality, improving resource-use efficiency, and promoting resilient crop production in the rice–chickpea cropping sequence, even though suggested methods increase output, maintenance of soil health and the ecosystem.



Source: Annual report, year 2023-24, AICRP on Chickpea, Directorate of Research, BCKV, Mohanpur, Nadia, West Bengal

Fig 4: Effect of natural, organic and recommended practice on yield attributes in chickpea. followed by rice.

Crop Diversification as a Method for Adapting to Climate Change

Numerous cereal, pulse, and oilseed crops are grown under a variety of cropping methods to maximise land use, improve soil fertility, and boost farm income in India's distinct agroclimatic zones (Hedayetullah *et al.*, 2018a; Roy *et al.*, 2025) [1, 34]. Based on productivity, acreage, and geographical significance, these crops are divided into major and minor categories. Rice (Rahaman *et al.*, 2022; Hedayetullah, 2022) [88], wheat (Triticum aestivum), maize (Zea mays) (Kundu *et al.*, 2020) [55], and sorghum (Sorghum bicolour) are important cereal crops. These are primarily grown in rotation or monocropping systems, such as sorghum-chickpea in semi-arid areas, rice-wheat in the Indo-Gangetic Plains, and rice-maize (Hedayetullah *et al.*, 2014a) [11]. Due to their drought resilience and nutritional importance, minor cereals like millets (finger millet, foxtail millet, and barnyard millet) are receiving more attention in nutri-cereal-based diversified systems, particularly in rainfed and tribal areas (Hedayetullah and Giri, 2020) [10].

Major oilseed crops that require less water are mustard (Brassica juncea) (Hedayetullah *et al.*, 2016) [4], groundnut (Arachis hypogaea) (Giri *et al.*, 2014) [11], and soybean (Glycine max). These are included into systems such as rice-mustard, groundnut-sorghum, and soybean-wheat (Zaman and Hedayetullah, 2018, Seth *et al.*, 2020) [30, 92]. In dryland areas, minor oilseeds like safflower, linseed, and niger are frequently produced as relay or intercrops. Diverse cropping systems that incorporate major and minor cereals, pulses, and oilseeds increase productivity, guarantee food and nutritional security, and preserve soil health (Zaman and Hedayetullah, 2025c; Zaman and Hedayetullah, 2018b) [29, 30]. Additionally, such variety helps India achieve sustainable agricultural intensification and increases resistance to climatic variability (Hedayetullah *et al.*, 2014b) [11]. India's cattle industry, which is essential to rural livelihoods and agricultural sustainability, depends heavily on fodder crops (Sadhukhan *et al.*, 2018) [90]. Fodder crops can be roughly divided into main and minor species based on farming systems and agroclimatic conditions (Hedayetullah, 2022) [15]. To guarantee year-round forage supply, including ginger crops, they are included into various farming systems, such as crop-livestock or agroforestry systems (Mukherjee and Hedayetullah, 2018a; Singh *et al*., 2024b) [32, 61]. Sorghum (Sorghum bicolour), maize (Zea mays), berseem (Trifolium alexandrinum) (Barik and Hedayetullah, 2018) [2], oats (Avena sativa) (Hedayetullah and Barik, 2012) [19], napier-bajra hybrid (Pennisetum glaucum × P. purpureum), and guar (Cyamopsis tetragonoloba) are important fodder crops. Because fenugreek has a high biomass production and nutritional value, they are widely grown (Zaman *et al*., 2018c) [120]. In northern India, berseem and oats predominate during the rabi season, whereas sorghum, maize, and cowpea are typical during the kharif season. In year-round cut-and-carry systems, particularly in intensive dairy zones, Napier grass and perennial species like Guinea grass are utilised. Senji (Melilotus spp.), Rhodes grass (Hedayetullah and Banerjee, 2018) [18], lablab (Lablab purpureus), canary grass (Ahmed and Hedayetullah, 2018) [1], sunhemp (Crotalaria juncea), Deenanath grass, anjan grass (Hedayetullah *et al*., 2018) [90], doob (Hedayetullah and Bandopadhyay, 2018) [17], and silage maize varieties (Hedayetullah and Zaman, 2018; Kundu *et al*., 2011, Kundu *et al*., 2015, 2018, 2020) [3, 52, 55, 120]. These are frequently produced as intercrops in orchards and agroforestry systems, on marginal lands, or in bunds. Due to their resistance to drought, lablab, senji, setaria, pangola, and stylo are particularly useful in semi-arid regions (Hedayetullah *et al*., 2018b; Hedayetullah *et al*., 2018c; Hedayetullah *et al*., 2012; 2018d, 2025c) [1, 19, 29]. Fodder crops are either grown as border crops (Johnson and doob grass) in horticulture-based systems or rotated or interplanted with cereals (such as berseem in wheat-rice systems) in integrated cropping systems (Hedayetullah and Zaman, 2018a; Hedayetullah and Zaman, 2018b) [120]. Dual-purpose cereals, such as multi-cut sorghum or maize, supply both grain and fodder in mixed farming systems (Mukherjee and Hedayetullah, 2018; Hedayetullah *et al*., 2018) [61]. Intercropping millets with fodder legumes improves soil fertility and forage quality (Ahmed and Hedayetullah, 2018) [1]. Major and minor fodder crops can be strategically incorporated into cropping systems to increase feed availability, improve soil health, and boost animal productivity—all of which contribute to resilient and sustainable farming systems in India (Hedayetullah and Zaman, 2018c; Zaman and Hedayetullah, 2019).(2018) [120, 130] Hedayetullah *et al*. Intercropping millets with fodder legumes improves soil fertility and forage quality (Ahmed and Hedayetullah, 2018) [1].

Soil Health, weed, water and Nutrient Management

Maintaining adequate soil fertility without the use of artificial inputs is one of the biggest problems in organic and natural rice cultivation. Natural farming has been observed to partially improve soil health due to the fast growth of heterotrophic microbial communities and flora as well as the increase in soil organic matter (Smith *et al*., 2020; Saharan *et al*., 2023) [127, 128]. A decrease in yield was recorded in some studies (Babalad *et al*., 2021; Naik *et al*., 2020), but not in others (Kumar *et al*., 2019; Duddigan *et al*., 2022) [131, 132, 133, 134].According to Hedayetullah and Kundu (2013), Basu *et al*. (2015), and Hedayetullah and Kundu (2021) [3, 23, 24], this consistency with natural farming principles helps to increase soil health, conserve biodiversity, and lessen environmental pollution.Arsenic enters the food chain through soil, water, and plant contamination (Zaman *et al*., 2018, 2018a; Hedayetullah *et al*., 2011, 2024, 2025) [29, 33, 49, 120].By lowering weed infestation and increasing crop yield, weed and water management under crop diversification is essential to sustainable agriculture (Dolai *et al*., 2013; Biswas *et al*., 2016; Dolai *et al*., 2019; Hedayetullah *et al*., 2024) [4, 6, 7, 32]. Crop rotation, intercropping, and sequential cropping are examples of diverse cropping techniques that control weeds by upsetting their life cycle and diminishing their dominance (Hedayetullah and Giri, 2021; Hedayetullah and Kumar, 2023) [21, 22]. Legumes, cover crops, and smother crops increase weed competition and reduce the accumulation of weed seed banks in the soil. Additionally, crop variety lessens reliance on herbicides, which lowers herbicide resistance and environmental pollution (Hedayetullah *et al*., 2025a) [34]. Diverse systems for integrated weed control enhance soil health, biodiversity, and long-term sustainability while guaranteeing better resource utilization and stable farm income (Kumar *et al*., 2015).

Ecological Management of Pests and Diseases

A range of homemade bio-pesticide formulations, including neemastra, agniastra, and bramhastra, are supported by natural farming (Shyam *et al*., 2019) [125]. These are used to control a variety of pests, including leaf rollers, fruit, stem and pod borer, mealy bugs, and sucking pests. Conservation biological control is promoted by landscape-level diversification, which includes planting refugia of sensitive cultivars, keeping field bunds with blooming plants (Cosmos, Sesamum, Parthenium-free bunds), and erecting bird perches to draw insectivorous birds. In comparison to conventionally managed fields, organic rice farms in the Gangetic plains have two to three times the diversity of arthropod predators, which naturally suppresses stem borers and leaf folders. An integrated biological pest management technique that is compatible with organic certification includes the use of light traps, pheromone traps, and mass release of *Trichogramma japonicum* egg parasitoids.

Market Opportunities and Value Chain Development

For small farmers growing traditional varieties, Participatory Guarantee Systems (PGS), a community-based organic certification framework approved by the Indian government, have reduced the certification barrier, allowing access to organic markets without the high expense and bureaucratic complexity of third-party certification (Zaman *et al*., 2026, 2026a, 2026b, 2026c) [111]. Several Assamese and Bengali FPOs reported notable revenue increase through online channels during and after the COVID-19 epidemic, indicating that e-commerce platforms and direct-to-consumer models had further expanded market reach.

Challenges and Constraints

In addition to agricultural practices, societal elements like social movements, governmental policies, markets, pedagogical procedures, leadership, and discourse also have a significant influence in the scaling up of NF (Khadse *et al*., 2018, 2019) [129, 130]. A major factor in the long-term expansion of NF practice is farmer-led and farmer-focused knowledge sharing. The widespread adoption of indigenous and aromatic rice production under natural and organic systems is hampered by a number of interconnected issues, notwithstanding the potential. The majority of traditional varieties generate 2-4 t/ha, but under ideal circumstances, HYVs produce 5-7 t/ha, making them less appealing to market-oriented farmers without premium price realisation. These yield discrepancies are still rather large. Farmers are exposed to revenue uncertainty throughout the transition phase (usually three years for organic certification), necessitating the use of financial support tools like credit lines or transition subsidies. Because traditional varieties are especially vulnerable to off-type contamination from nearby HYV fields through pollen drift, seed purity and genetic erosion continue to be risks

Notwithstanding the potential, a number of interconnected obstacles prevent indigenous and fragrant rice farming under natural and organic methods from being widely adopted. The majority of traditional varieties generate 2-4 t/ha, but under ideal circumstances, HYVs produce 5-7 t/ha, making them less appealing to market-oriented farmers who do not realise premium prices. These yield differences are nevertheless substantial. Farmers are subject to revenue uncertainty throughout the transition period (usually three years for organic certification), necessitating the use of financial support tools like credit lines or transition subsidies. Because traditional varieties are especially vulnerable to off-type contamination from nearby HYV fields through pollen drift, seed purity and genetic erosion are persistent risks.

Future Directions: Priorities and Suggestions for Policy

Government and agriculture officials have planned a seed festival to increase public awareness. Now, even farmers are offering their services to protect ancient types. In this way, we may safeguard our customary variety for the future as well as the present. This effort to promote sustainable agriculture will assist both the preservation of our traditional rice types and the creation of new rice varieties that are resistant to drought and salt (Patra *et al*., 2025f) [13]. Coordinated work across the areas of research, policy, and market is necessary to fully realise the promise of indigenous and aromatic rice in crop-diversified organic and natural systems. To preserve genetic variety and find strains with increased adaptability without sacrificing conventional quality features, community seed banks and participatory varietal selection programs must be strengthened (Zaman and Hedayetullah, 2026, 2026a, 2026b, 2026c) [111]. The characterisation of soil microbiome dynamics under natural farming practices and their interaction with traditional variety rhizospheres is an area that is still in its infancy and should be funded by research institutions.

Policy frameworks should incorporate assistance for organic and natural farming into mainstream agricultural schemes, extend crop insurance coverage to migrating organic farmers, and acknowledge traditional knowledge through sui generis legal safeguards. Traditional variety production should be specifically targeted as a priority crop category in national natural farming missions, such as India's BharatiyaPrakritik Krishi Paddhati plan (Zaman *et al*., 2018b, 2018c) [120]. In addition to supporting farmer livelihoods, public procurement of organically cultivated indigenous rice for welfare programs (midday meals, public distribution systems) would enhance poor persons' access to nutrients.

Conclusion

All things considered, combining natural and organic farming methods, diverse cropping systems, and indigenous and fragrant rice growing offers a feasible route toward sustainable agricultural intensification. This strategy improves ecosystem resilience, food and nutritional security, rural livelihoods, and climate adaption in addition to protecting important plant genetic resources and traditional knowledge. To produce rice that is resilient, ecologically conscious, and economically sustainable for future generations, these integrated systems should be given top priority in agricultural policies and research.

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