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Conservation of Agrobiodiversity through Women's Indigenous Knowledge: The Case of Red Rice in Uttarakhand

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Abstract: Red rice (Oryza sativa L.), locally known as Laal Dhaan in Uttarakhand, is a nutritionally rich, ecologically resilient, and culturally significant crop increasingly threatened by agricultural modernisation, market pressures, and the erosion of indigenous knowledge. This narrative review synthesises literature from Scopus, Web of Science, and Google Scholar to examine the interrelationship between traditional red rice cultivation, women's indigenous knowledge systems, and nutritional and ecological sustainability in the Himalayan region. Drawing on 42 studies across three themes — traditional cultivation and seed preservation, women's knowledge custodianship, and nutritional and ecological sustainability — the review demonstrates that women are the primary custodians of red rice diversity in Uttarakhand, responsible for seed selection, post-harvest processing, and intergenerational knowledge transmission. Their contributions vary significantly across geographical and socio-economic contexts but remain largely unrecognised in formal agricultural policy. Red rice is nutritionally superior to polished white rice in dietary fibre, minerals, and bioactive compounds, yet its cultivation continues to decline. The review advances an integrated, gender-sensitive framework linking biodiversity conservation, nutritional security, and indigenous knowledge, and recommends community seed banks, women's cooperatives, value chain development, and Geographical Indication (GI) registration to sustain red rice systems in Uttarakhand.

Keywords: Red Rice • IKS • Agrobiodiversity Conservation • Traditional Farming Systems • Women's Knowledge Custodianship • Nutritional Sustainability • Himalayan Agriculture • Uttarakhand

Introduction

Rice (Oryza sativa L.) is not only the world's most important staple food but also a carrier of cultural traditions, religious practices, and indigenous healing systems across South and Southeast Asia (Ahuja et al 2008; Fukagawa & Ziska 2019). Among India's extraordinary diversity of rice landraces, pigmented varieties — red, black, and purple — stand out for their nutritional richness and health-promoting potential (Samyor et al 2017; Arsha et al 2021). These are living expressions of indigenous knowledge, ecological wisdom, and cultural identity. Yet high-yielding varieties, chemical-intensive farming, and market-driven agriculture are dismantling traditional food systems, eroding crop diversity, and leaving communities more nutritionally and ecologically vulnerable (Akinola et al 2020; Lara 2025). Nowhere is this more evident than in Uttarakhand, where mountain farming traditions built on terrace cultivation, mixed cropping, and the celebrated Barahnaja system are giving way to modern monocultures (Chamoli et al 2024). At the heart of this erosion is the declining cultivation of red rice (Laal Dhaan) — a nutritionally rich, ecologically resilient grain valued for its Ayurvedic therapeutic properties and deep cultural roots in Uttarakhand's food heritage (Thakur et al 2020; Umadevi et al 2012). Critically, what goes unnoticed is who holds these systems together: women. In rural Uttarakhand, women select and store seeds, manage crops, process harvests, and prepare traditional foods. They identify rice landraces by grain colour, aroma, and cooking quality, and maintain cultivation calendars transmitted

through practice. They keep red rice alive in daily and ceremonial life — yet their contributions remain largely invisible in formal agricultural policy (Singh et al 2013; Uniyal et al 2011). Existing research has examined traditional cultivation, women's knowledge, and nutritional significance as separate subjects. Very little work has connected these dimensions — particularly for red rice in Uttarakhand. This review addresses that gap by integrating three interdependent lenses: traditional cultivation and seed preservation, women's indigenous knowledge, and nutritional and ecological significance. These dimensions are mutually constitutive — the nutritional value of red rice depends on the processing knowledge that preserves it; its ecological resilience depends on seed knowledge that maintains its diversity; and both depend on the women whose labour and wisdom sustain the entire system. This study therefore aims to: (1) synthesise literature on traditional red rice cultivation and seed preservation in Uttarakhand; (2) examine women's roles in indigenous knowledge custodianship; and (3) analyse the nutritional and ecological significance of red rice within traditional food systems — contributing an integrated, gender-sensitive perspective largely missing from the current literature.

Methodology

Research Design: This study employs a narrative literature review to synthesise existing research on women's indigenous knowledge, traditional red rice cultivation, and nutritional sustainability in Uttarakhand. A narrative approach was selected over a systematic review given the interdisciplinary nature of the topic — spanning agricultural sciences, food science, gender studies, and indigenous knowledge systems — which does not readily accommodate a single rigid research protocol. This method allows broader interpretation of evidence across disciplines and is consistent with established practice in reviews of traditional food systems and agrobiodiversity conservation (Joseph & Turner 2020; Akinola et al 2020).

Literature Search Strategy: Literature was searched across Scopus, Web of Science, and Google Scholar, covering peer-reviewed studies published between 2010 and 2025. Select foundational studies published before 2010 were retained when essential for background context (Kala et al 2008; Mehta et al 2009). Search strings included:

- ("red rice" OR "pigmented rice") AND "Uttarakhand"
- "Indigenous knowledge" AND "rice farming" AND "Himalayan region"
- "Women in agriculture" AND "traditional knowledge" AND "seed preservation"
- "Traditional food systems" AND ("sustainability" OR "agrobiodiversity")
- "Laal Dhaan" OR "red rice Himalaya" AND "nutrition"

Inclusion and Exclusion Criteria: Studies were included if they addressed: red rice or pigmented rice cultivation and conservation; traditional farming systems and agrobiodiversity in the Himalayan region; women's roles in indigenous knowledge and agricultural practices; seed preservation and traditional food systems; or the nutritional and ecological significance of traditional rice varieties. Peer-reviewed journal articles, book chapters, and government or institutional reports in English were considered, with emphasis on studies from Uttarakhand and the broader Indian Himalayan region. Studies from other regions were included only where they provided relevant comparative insights unavailable in Himalayan-specific literature. Studies were excluded if they were duplicate records, lacked full-text availability, focused exclusively on modern high-yielding varieties without reference to traditional practices, or were not directly relevant to review objectives. Conference abstracts, editorials, and opinion pieces were also excluded.

Study Selection and Thematic Analysis: Approximately 180 records were initially identified. Following title and abstract

screening, full-text assessment, duplicate removal, and application of inclusion/exclusion criteria, 42 studies formed the primary evidence base. Additional contextual references were incorporated to situate findings within broader food systems and gender literature. Retained literature was analysed using inductive thematic analysis — each study was read in full and coded for primary focus, key findings, geographical context, and relevance to review objectives. Codes were iteratively grouped into three core themes: traditional cultivation practices and seed preservation; women's indigenous knowledge systems; and the nutritional and ecological significance of red rice. Studies addressing multiple themes were coded under all relevant categories. Contradictions between studies — particularly varying estimates of traditional crop decline rates and differing assessments of women's decision-making authority — were noted and are discussed explicitly in relevant sections. Key research gaps were similarly identified through this process, including the limited empirical documentation of gender–conservation intersections in the Himalayan context and the absence of longitudinal studies tracking changes in women's indigenous knowledge over time.

Result and Discussion

Traditional Cultivation Practices and Seed Preservation

Traditional rice cultivation in Uttarakhand reflects generations of knowledge built through adaptive farming in Himalayan environments, characterised by mixed cropping, minimal chemical inputs, and ecological balance rooted in indigenous technical knowledge (Chowdhury et al 2026). Central to this tradition is the Barahnaja system — a sophisticated mixed cropping practice growing twelve or more crop species simultaneously during the monsoon season. Barahnaja reflects a nuanced understanding of inter-crop support — fixing nitrogen, distributing livelihood risk, and ensuring nutritional diversity. Farmers in the central Himalaya cultivate over 100 types of rice alongside 170 types of kidney beans within this system, representing one of the most diverse agrobiodiversity hotspots on the Indian subcontinent (Chowdhury et al 2026). Red rice sits at the centre of this system, contributing to both dietary diversity and ecological health.

The Sari system, a complementary cropping practice of the Garhwal Himalaya, further supports red rice conservation by distributing crops vertically across hill elevations through structured two-year rotation cycles (Chowdhury et al 2026). Together, Barahnaja and the Sari system constitute an integrated indigenous agricultural framework within which red rice landraces have been maintained across generations. Women's roles in seed selection, drying, storage, and variety-specific cultivation calendars have been the primary mechanism for preserving red rice genetic diversity (Sati & Juyal 2008; Chowdhury et al 2026). Red rice is genuinely well suited to Himalayan conditions — tolerating marginal soils, unpredictable rainfall, and low-input farming in ways modern varieties cannot (Aditya et al 2024).

However, the evidence base for traditional cultivation has important limitations. Much of the available literature on Barahnaja and the Sari system is descriptive rather than experimental; rigorous agronomic data comparing yields, soil health, and nutritional outputs between traditional and modern systems in Himalayan contexts remain scarce (Chamoli et al 2024; Chowdhury et al 2026). This limits the persuasiveness of ecological arguments to policymakers oriented toward productivity metrics and represents a significant gap that requires field-based research. Red rice has nonetheless been steadily displaced by government-promoted high-yielding varieties and a market that rewards polished white rice. Traditional cropping patterns such as Barahnaja have declined by approximately 60% due to social, economic, and climatic pressures (Maikhuri et al 1997, as cited in Chowdhury et al 2026),

while the area under traditional crops has fallen by 80–100% in some parts of Uttarakhand over the past two decades (Sati & Juyal 2008). These varying estimates reflect differences in study location, time period, and methodology rather than a coherent regional picture, and the absence of systematic district-level monitoring means the true extent of red rice landrace loss remains undocumented—a gap that requires participatory landrace mapping with women farmers as co-investigators. As male outmigration accelerates, intergenerational transmission of indigenous knowledge is further disrupted, placing seed systems at heightened risk of irreversible loss (Chowdhury et al 2026).

Comparative evidence from India underscores that this is not an isolated pattern. The Apatani wet rice system of Arunachal Pradesh combines traditional irrigation, organic farming, and rice-fish culture in a model recognised for ecological efficiency (Kala et al 2008), while traditional organic rice farming in Kerala has shown clear cultural and ecological value yet declined under comparable market pressures (Krishnankutty et al 2021). These cases illustrate a broader and urgent pattern of indigenous knowledge loss; however, Uttarakhand's specific agrobiodiversity heritage demands conservation responses rooted in its own ecological and socio-cultural context.

Table 1. Traditional Rice Cultivation Systems and Their Relevance to Red Rice Conservation in India

Traditional System	Region	Key Characteristics	Relevance to Red Rice Conservation
Barahnaja	Uttarakhand, Garhwal Himalaya	Mixed cropping of 12+ species; low external inputs; rainfed agriculture	Directly supports red rice landrace diversity; maintains ecological balance essential for low-input cultivation
Sari System	Uttarakhand, Garhwal Himalaya	Two-year crop rotation across hill elevations; irrigated and rainfed land; vertical distribution of crops	Preserves local landraces including red rice through structured seasonal rotation
Indigenous Seed Systems	Uttarakhand, Hill Communities	Women-led seed selection, drying, storage, and cultivation calendars; intergenerational knowledge transmission	Primary mechanism for maintaining red rice genetic diversity across generations
Apatani Wet Rice System	Arunachal Pradesh	Traditional irrigation, organic farming, rice-fish culture; internationally recognised for ecological efficiency	Comparative model illustrating how indigenous rice systems sustain ecological balance
Traditional Organic Rice Farming	Kerala	Community-based organic farming; strong cultural and ceremonial significance	Illustrates wider pattern of indigenous rice decline under market pressure — comparable to Uttarakhand

Note. Compiled from Chamoli et al. (2024); Chowdhury et al. (2026); Sati & Juyal (2008); Kala et al. (2008); and Krishnankutty et al. (2021).

Women's Indigenous Knowledge in Red Rice-Based Food Systems

Women's contributions to food systems in Uttarakhand are neither uniform nor static; they are shaped by diverse socio-economic and geographical conditions that must be understood before designing conservation interventions. In remote hill regions where agriculture is predominantly subsistence-oriented and male outmigration is prevalent, women often manage the entire agricultural cycle — seed selection, crop management, post-harvest processing, and food preparation (Chowdhury et al 2026). Census data indicate that women constitute 56% of cultivators in Uttarakhand and contribute more than 85% of agricultural labour, working 15–18 hours daily (Sati & Juyal 2008). Their knowledge is fundamental to system resilience — they identify rice landraces by grain colour, aroma, and cooking quality, and their practices are rooted in traditional knowledge transmitted across generations rather than formal education, most visibly in the Barahnaja

system where over 100 rice types are maintained through women's seed-saving practices (Chowdhury et al 2026). In contrast, women in more accessible areas with better market connectivity have demonstrated the capacity to move beyond subsistence into collective entrepreneurship. The Rawain Women's Cooperative Federation (RWCF) in Yamuna Valley is instructive — women's self-help groups engaged in grading, processing, packaging, and marketing of traditional organic crops, achieving an annual turnover of approximately Rs 45 million and expanding employment from six to nearly 300 days per year (Sati & Juyal 2008). This demonstrates that where institutional support and market linkages are available, women's roles can extend into active stewardship of agrobiodiversity within market-oriented systems. However, the RWCF model represents a well-supported intervention in a specific context and cannot be assumed replicable in remote communities without comparable institutional infrastructure. Socio-economic factors — landholding size, educational attainment, household income, and access to institutional support — further differentiate women's roles across the region (Singh et al 2013), and these differences must be central to conservation intervention design. Women's post-harvest knowledge deserves particular emphasis. Traditional dehusking methods that preserve the bran layer are key to red rice's nutritional superiority. The shift toward mechanical milling is more pronounced in accessible lowland areas with greater market integration, whereas traditional processing knowledge is better retained in remote hill communities. Where mechanical milling displaces traditional methods, the bran layer is lost, leading to significant declines in dietary fibre, micronutrients, and bioactive compounds (Devi & Badwaik 2022) — a loss that is simultaneously technical, nutritional, and cultural. Women also prepare traditional foods and fermented dishes that sustain red rice's significance in daily and ceremonial life (Thakur et al 2020), though these practices are increasingly precarious in economically marginalised households.

Cross-regional evidence supports the broader argument that women's seed selection consistently maintains higher varietal diversity. Molina et al. (2022) found that in Andean Peru, women's managed fields showed significantly greater varietal diversity than male-managed fields. While the Peruvian context involves potato rather than rice conservation across different ecological conditions, this evidence illustrates a robust global pattern: women's indigenous knowledge supporting crop diversity. Region-specific studies examining the relationship between women's seed practices and red rice landrace diversity in Uttarakhand are absent, representing a critical gap for future research. A notable limitation of the existing literature is its tendency to document women's contributions broadly without examining how constraints such as land tenure insecurity, caste hierarchies, time poverty, and household composition shape women's actual agency in seed conservation decisions — rather than merely their labour contributions. While male outmigration has increased women's agricultural responsibilities across hill communities, its effects are uneven: in some households, it has expanded women's de facto decision-making authority; in others, it has deepened resource constraints without commensurate recognition (Chowdhury et al 2026). No longitudinal studies currently track how women's knowledge systems change as outmigration accelerates — evidence essential for designing interventions responsive to dynamic realities rather than static assumptions.

Table 2. Women's Roles in Red Rice-Based Food Systems and Their Sustainability Contributions

Activity	Women's Role	Contribution to Sustainability
Seed Conservation	Selection, drying, and storage of seeds	Maintains genetic diversity and landrace conservation

Cultivation Practices	Sowing, transplanting, weeding, and harvesting	Supports low-input and sustainable production systems
Post-Harvest Processing	Drying, dehusking, milling, and storage	Preserves nutritional quality of red rice
Food Preparation	Traditional cooking and medicinal uses	Enhances dietary diversity and cultural continuity
Knowledge Transfer	Sharing skills and practices across generations	Sustains indigenous knowledge and food systems

Note. Compiled from Gwandure and Lukhele-Olorunju (2023); Molina et al. (2022); Singh et al. (2013); and Uniyal et al. (2011).

Nutritional Significance of Red Rice

Red rice retains its bran layer, which carries dietary fibre, B-complex vitamins, essential minerals — iron, zinc, magnesium, and calcium — and bioactive compounds including phenolics, anthocyanins, proanthocyanidins, and gamma-oryzanol (Arsha et al 2021; Devi & Badwaik 2022). Milling and polishing strips these away. The nutritional gap between red and white rice is substantial and matters especially for Uttarakhand communities facing anaemia, diabetes, and micronutrient deficiency. The antioxidant and anti-inflammatory properties of red rice bran have been shown to protect against cardiovascular disease, type 2 diabetes, obesity, and certain cancers (Sudan et al 2023; Oliveira et al 2026). Its moderate-to-low glycaemic index is particularly relevant to India's growing diabetes burden. Ayurveda has long recognised the therapeutic value of red rice, known as Raktashali, and recent studies have supported several traditional claims by demonstrating antioxidant, anti-inflammatory, and metabolic health benefits (Umadevi et al 2012; Kowsalya et al 2022). However, the nutritional evidence requires careful interpretation. Most studies documenting superior antioxidant, mineral, and fibre content have been conducted under controlled laboratory conditions using specific landrace samples, and findings may not translate uniformly across all red rice varieties grown in Uttarakhand, given considerable genetic diversity within this category. Glycaemic index values also vary across studies depending on variety, processing method, cooking technique, and study population (Devi & Badwaik 2022; Kowsalya et al 2022). Furthermore, while Ayurvedic traditions ascribe significant therapeutic properties to red rice, scientific validation remains largely preliminary — studies demonstrating antidiabetic, anti-inflammatory, and cardiovascular benefits are predominantly in vitro or animal-based, with limited clinical trial evidence in human populations (Sudan et al 2023; Oliveira et al 2026). This gap between traditional knowledge and scientific validation is a productive space for collaborative research involving indigenous knowledge holders and food scientists. Community-based dietary studies and clinical research in Himalayan populations are needed before definitive health claims can be made.

Ecologically, the Barahnaja system's mixed cropping, organic nutrient management, and on-farm seed conservation support healthy soils, diverse microbial communities, and the agrobiodiversity that maintains farming resilience (Chamoli et al 2024). Red rice's genetic adaptations to Himalayan stress conditions — developed over centuries of farmer selection — are only beginning to be appreciated by modern breeding programmes, and its survival depends almost entirely on women's seed knowledge and continued in-situ cultivation (Aditya et al 2024; Zhu et al 2024). Ecological benefits of traditional systems are, however, largely documented through descriptive case studies; systematic field research comparing soil health, water retention, and biodiversity outcomes between traditional and modern cultivation across Uttarakhand's agro-climatic zones would substantially strengthen the evidence base for conservation advocacy. Losing red rice is therefore not merely a cultural loss — it

represents a failure of food systems to honour their own sustainability commitments.

Table 3: Comparative Nutritional and Functional Properties of Red Rice and Polished White Rice

Parameter	Red Rice	White Rice	Health Significance
Processing	Bran retained	Bran removed	Higher nutrient retention in red rice
Dietary fibre	Higher	Lower	Supports gut health and glycaemic control
Minerals (Iron, Zinc, Magnesium)	Higher	Lower	Helps improve micronutrient intake
Antioxidant and Bioactive compound	Rich in phenolics, anthocyanins, and gamma-oryzanol	Minimal	Provides antioxidant and anti-inflammatory benefits
Glycaemic Index	Moderate–low	High	Better suited for metabolic health
Functional Properties	Antidiabetic, antioxidant, anti-inflammatory	Limited	Potential functional food benefits

Note. Compiled from Arsha et al. (2021); Devi and Badwaik (2022); Hegde et al. (2013); Oliveira et al. (2026); Sudan et al. (2023); and Umadevi et al. (2012).

Ecological Sustainability of Traditional Red Rice Systems

Traditional red rice cultivation plays an important role in maintaining the ecological balance of Himalayan farming systems. Practices such as mixed cropping under the Barahnaja system, organic nutrient management, and traditional seed conservation help sustain soil fertility, biodiversity, and long-term agricultural resilience (Chamoli et al 2024). By cultivating a range of crops and traditional rice varieties together, farmers reduce production risks and support a more diverse and stable agroecosystem. Red rice is naturally suited to the challenging conditions of the Himalayan region, including marginal soils, limited inputs, and variable rainfall, and its ability to thrive under these conditions reflects generations of farmer knowledge and selection, making it a valuable resource for climate-resilient agriculture (Aditya et al 2024; Zhu et al 2024). However, the ecological benefits of traditional red rice systems are largely documented through descriptive case studies rather than controlled field trials, and the lack of comparative data between traditional and modern systems limits the strength of ecological claims that can currently be made. Systematic research examining soil health, water retention, and biodiversity outcomes under traditional versus modern cultivation in Uttarakhand's diverse agro-climatic zones would considerably strengthen the evidence base for conservation advocacy.

Threats to Indigenous Red Rice Systems

Indigenous red rice systems face multiple interacting threats that collectively drive the erosion of crop diversity and associated knowledge. Expansion of high-yielding varieties, market-driven practices, and shifting dietary preferences have contributed to the decline of landraces, while subsidised rice distribution through the public distribution system has reduced the economic incentive to cultivate traditional varieties (Blakeney et al. 2020; Krishnankutty et al. 2021; Sati & Juyal 2008). Erosion of indigenous knowledge among younger generations due to migration and socio-economic change further weakens the human foundation on which traditional farming depends (Uniyal et al 2011; Chowdhury et al 2026). Climate variability — erratic rainfall, rising temperatures — poses additional challenges to traditional cultivation systems in the Himalayan region (Zhu et al 2024). Critically, these threats do not operate in isolation or uniformly across Uttarakhand. Market integration affects lowland and accessible areas more rapidly than remote hill villages, while climate variability disproportionately affects higher-altitude farming. Outmigration combined with market pressure simultaneously removes agricultural labour and cultural motivation for traditional

cultivation, while climate stress further destabilises the ecological conditions that make red rice viable. This systems-level interaction among threats is largely absent from current research, creating a significant analytical gap that conservation responses must address.

Conclusion

This review provides a novel and integrated perspective on the interconnected roles of traditional red rice cultivation, women's indigenous knowledge systems, and nutritional sustainability in Uttarakhand. While previous studies have examined these themes independently, the present synthesis demonstrates that they are fundamentally interdependent. The nutritional benefits of red rice rely on traditional processing practices that preserve its bioactive compounds, while its ecological resilience depends on indigenous seed selection and conservation practices. Both processes are sustained largely by women, whose labour, skills, and knowledge underpin the entire production system. This integrated framework, largely absent from existing literature on Himalayan agrobiodiversity, represents the principal contribution of this review.

Evidence compiled from 42 studies confirms that women serve as the primary custodians of red rice diversity in Uttarakhand. Their responsibilities extend from seed selection and crop management to post-harvest processing and the transmission of knowledge across generations. However, women's roles are shaped by local socio-economic conditions. In remote subsistence-based communities, women continue to bear the primary responsibility for agricultural production and knowledge preservation. In contrast, women in regions with greater market access have expanded their participation into collective enterprises, exemplified by the activities of the Rawain Women Cooperative Federation (RWCF) in the Yamuna Valley (Sati & Juyal, 2008). Factors such as landholding size, education, and institutional support significantly influence women's participation in agricultural decision-making (Singh et al., 2013).

Red rice possesses higher levels of dietary fibre, minerals, antioxidants, and bioactive compounds than polished white rice, offering potential benefits in addressing anaemia, diabetes, and micronutrient deficiencies (Arsha et al., 2021; Devi & Badwaik, 2022; Sudan et al., 2023). Importantly, these nutritional advantages depend on traditional processing methods, particularly stone dehusking, which retains the nutrient-rich bran layer. The replacement of these practices by mechanical milling not only reduces nutritional quality but also contributes to the erosion of women's traditional knowledge.

The review further identifies major research gaps, including inadequate documentation of threatened landraces, limited community-based nutritional studies, a lack of longitudinal research on the impacts of migration on indigenous knowledge, and insufficient understanding of the combined effects of market integration, climate change, and socio-economic transformation. Conservation of red rice therefore requires protecting both the crop and the cultural knowledge systems that sustain it, with women positioned as central actors in conservation policy, seed governance, breeding programmes, and value-chain development.

Policy Implications

The findings of this review have important implications for agricultural policy, biodiversity conservation, and rural development in Uttarakhand. Women constitute nearly 56% of cultivators and contribute more than 85% of agricultural labour in the hill regions (Sati & Juyal, 2008), yet their knowledge and contributions remain inadequately represented in formal agricultural planning, extension services, and policy frameworks. Addressing this gap is not only a matter of social equity but also a prerequisite for the effective conservation of traditional crops and associated knowledge systems. Agricultural development programmes should

formally recognise women's expertise in seed conservation, crop cultivation, post-harvest processing, and traditional food preparation. Gender-responsive extension services must be designed to accommodate women's schedules and mobility constraints, while indigenous knowledge related to red rice cultivation should be systematically documented through state biodiversity registers and local knowledge repositories.

Community seed banks governed primarily by women's groups represent a practical and sustainable strategy for conserving red rice diversity. Such institutions should facilitate seed exchange, maintain records of landrace characteristics, and support participatory varietal selection programmes that allow women farmers to evaluate and preserve locally adapted varieties. Long-term financial support can be channelled through existing initiatives such as the Paramparagat Krishi Vikas Yojana (PKVY) and community biodiversity register programmes to ensure continuity beyond short-term projects.

The experience of the Rawain Women Cooperative Federation (RWCF) demonstrates that women-led collectives can generate significant economic benefits while simultaneously preserving traditional agricultural practices (Sati & Juyal, 2008). Similar cooperative models should be promoted across red rice-growing districts through institutional capacity building, market facilitation, and access to NABARD-supported credit. Investments in value-chain development should prioritise traditional processing infrastructure, particularly stone dehusking technologies that preserve the nutrient-rich bran layer and maintain the nutritional advantages of red rice (Devi & Badwaik, 2022). Training in quality grading, packaging, branding, and marketing can further improve market access and profitability.

Obtaining Geographical Indication (GI) status for Uttarakhand red rice would strengthen its market identity, enhance consumer recognition, and create premium-value opportunities. Women farmers and their cooperatives should be acknowledged as primary custodians and beneficiaries within such frameworks. Policy measures including minimum support price procurement, incentives for maintaining landrace diversity, and incorporation of red rice into public distribution systems, school meal programmes, and nutrition interventions can help reverse the decline of traditional cultivation. Additionally, agro-tourism initiatives linked to Barahnaja farming systems may provide supplementary income while promoting awareness of indigenous crops and their ecological significance (Chowdhury et al., 2026). Collectively, these measures offer an integrated policy framework that strengthens women's roles, conserves agrobiodiversity, and promotes nutritional security and sustainable rural livelihoods across Uttarakhand.

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