

PROGYAN COMMUNIQUE
The Triannual Newsletter
July 2025
VOLUME 2 ISSUE 1



Seeds of Change: Resilient Agriculture and Agrobiodiversity

Published by
Progyan Foundation for Research and Innovation (PFRI)
ISO 14001: 2015

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EDITOR'S CHOICE



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Nature's Invoice: Dharali Pays the Price

The village of Dharali in Uttarkashi district of Uttarakhand was devastated by a terrible flash flood in just a few minutes. Numerous houses, shops, bridges and roads were swept away by the rapid flow of the river. Initially, allegations were made that 'cloudburst' or cloud-breaking rain was behind this disaster. But the data from meteorologists tells a different story.

In meteorology, it is said that if at least 100 mm (10 cm) of rain falls in an hour over a 10 km length and width of an area, it can be called a cloudburst. But in the 24 hours before the disaster, only 9 mm of rain fell in Harsil, 11 mm in Bhatwari and 27 mm in Uttarkashi. Which is far from the definition of a cloudburst.

According to geologists and environmentalists, the main cause of this disaster is man-made infrastructure, especially the Chardham Highway project, which is being built at a cost of Rs 12,000 crore. The construction of this 890 km long road connecting Kedarnath, Badrinath, Gangotri and Yamunotri. 690 hectares of forest land destroyed, 55 thousand trees destroyed, 20 million cubic meters of soil removal.

Cutting such a huge mountain has completely disrupted the balance of nature. In the last few years, 811 landslides have been recorded in the area adjacent to this highway, of which 81% occurred within 100 meters of the road.



Img: AI Generated

Uttarakhand extends from 800 meters to 6900 meters above sea level. The land slopes mainly towards the southwest. There are more than 1200 glacial lakes here, many of which have weak banks and are at risk of erosion. Due to climate change, glaciers are melting rapidly, resulting in an increase in the number and size of lakes. This is an alarming sign for this region.

The soil of Uttarakhand contains brittle layers rich in phyllite and mica. These layers have been exposed by mountain erosion, which has led to major landslides even with a little rain.

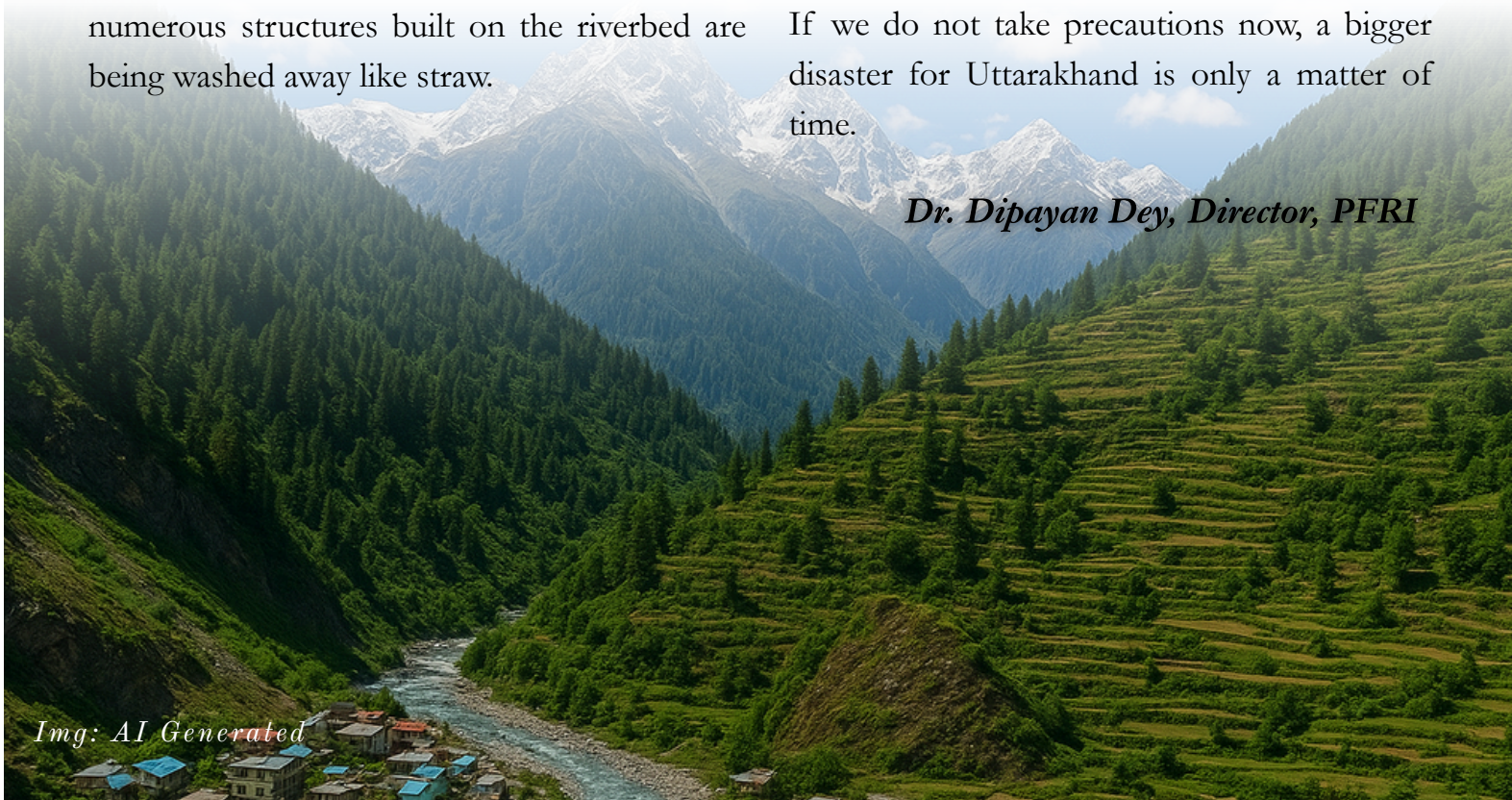
To increase tourism, a large number of hotels, shops, resorts and other structures have been built along the riverbed. When the river widens during the monsoon or when the flash flood subsides, all these structures are washed away instantly, increasing the level of damage. Video footage from Dharali also shows that numerous structures built on the riverbed are being washed away like straw.

In 2013, after the Kedarnath disaster, the Chorabatal lake broke its banks and a huge amount of water came down, washing away numerous structures built on the riverbanks. Uttarakhand did not learn any lessons from that terrible experience. The situation in 2025 has proven that if riverbed construction and hill cutting continue, history will repeat itself.

According to geologists, similar disasters can happen at any time in areas of Uttarakhand like Harsil, Uttarkashi, Barkot, Rudrapur, Devprayag, Chamoli, Guptkashi, etc. If unplanned development and environmental neglect are added to natural disasters, the danger increases manifold.

This devastation of Dharali is not just the result of natural forces; rather, it is the combined result of human ignorance, construction by cutting down mountains, deforestation, uncontrolled construction on river banks, and the fragility of the landscape. If we do not take precautions now, a bigger disaster for Uttarakhand is only a matter of time.

Dr. Dipayan Dey, Director, PFRI



Img: AI Generated



CURRENT CONTEXT



Harvest on the Edge: Securing South Asia's Food Future through Coastal Agriculture



Introduction: The Precarious Bounty

In the mud-flats of the Indian Sundarbans, a farmer named Anjali digs a small pit in her field. She tastes the water that seeps in its salty. For generations, this land has yielded the rice that fed her family. Now, it offers a saline warning of a creeping crisis. Anjali's story is not unique; it is the lived reality for millions across South Asia's vast and fertile coastlines. This region, stretching from the Indus delta in Pakistan to the Ganges-Brahmaputra-Meghna delta in Bangladesh and encompassing the coasts of India and Sri Lanka, is home to over a quarter of a billion people. As Neumann and his team reported in 2015, in his paper any of them depend directly on agriculture for their survival (*Neumann et al., 2015*). This 'precarious bounty' is now on the front-line of a global climate emergency, facing an existential threat that could reshape the future of food for the entire subcontinent. Yet, amidst the crisis, a story of incredible resilience and ingenuity is unfolding. Farmers, scientists, and communities are turning this climate frontline into a forefront of agricultural innovation.

From the Sundarbans delta of India and Bangladesh, to the Krishna–Godavari plains of India, the Indus delta of Pakistan, and the fragile islands of Sri Lanka and Maldives, coastal agriculture sustains millions through rice, fisheries, and aquaculture. Yet, these zones lie directly in the path of climate change. As highlighted in the Intergovernmental Panel on Climate Change's 2021 report, rising seas, salinity, and extreme events threaten both food production and livelihoods (*IPCC, 2021*)

The Closing vise: A climate assault

The agricultural heartlands of coastal South Asia are being squeezed by a three-pronged climate assault, a slow-motion disaster pushing traditional farming systems to their breaking point.

Coastal Agriculture Under Pressure

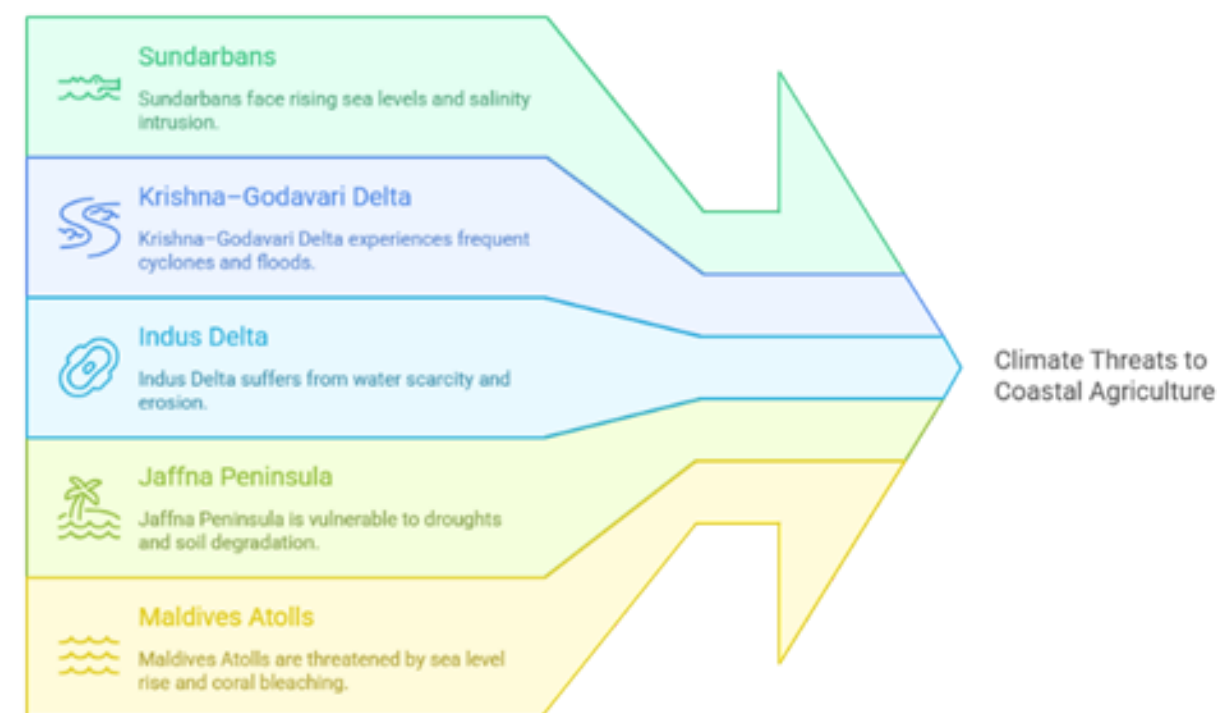


Figure 1 Climate change impacts on coastal agriculture

THE SALT TIDE

The most insidious threat is salinization. As global temperatures rise, melting glaciers and expanding oceans cause the sea level to rise, particularly fast in the Bay of Bengal. This allows saltwater to push further inland during high tides and storm surges, contaminating the freshwater aquifers and soils farmers rely on. As explained by Maas and Hoffman in their landmark 1977 study on crop salt tolerance, once soil salinity crosses a threshold of 4 Deci Siemens per meter (dS/m), the yields of staple crops like rice begin to plummet (*Maas & Hoffman, 1977*).

The salt essentially dehydrates the plant from the root up, stunting its growth and killing the harvest. This 'salt tide' is silently turning vast tracts of once-productive paddy fields into barren, salt-crusted land. The Intergovernmental Panel on Climate Change (2021) warns that global sea levels could rise by 0.6 to 1.1 meters by 2100, with the Bay of Bengal among the most vulnerable hotspots. This is already visible in Bangladesh, where 1.5 million hectares of farmland are affected by salinity (*World Bank, 2020*).

THE FURIOUS SKY

The warming ocean surface acts as fuel for tropical storms. The Intergovernmental Panel on Climate Change (IPCC) reports with high confidence that the intensity and precipitation from cyclones in the North Indian Ocean have increased and will continue to do so (IPCC, 2021). Recurrent cyclones such as Amphan (2020) and Mocha (2023) have devastated rice fields, shrimp farms, and fisheries in Bangladesh, India, and Myanmar. In India alone, the World Bank (2020) estimates that storm surges cause agricultural losses of between US\$3–5 billion every year.

This not only flatten standing crops with ferocious winds but also cause catastrophic flooding and saltwater inundation that can render land infertile for years. For coastal farmers, the sky is no longer just a source of life-giving rain but also a harbinger of fury that can wipe out a year's livelihood in a single day.

GUARDIANS OF THE ESTUARY: REVIVING 54 INDIGENOUS PADDY VARIETIES FOR CLIMATE RESILIENCE IN THE INDIAN SUNDARBAN

In the cyclone-prone Indian Sundarban, Progyan Foundation for Research and Innovation and the South Asian Forum for Environment systematically revived and cultivated 54 traditional salt-tolerant paddy landraces across 24 pilot plots between 2021–2024. These landraces such as ‘Nona Bokra’, ‘Darsal’, and ‘Talmugur’ demonstrated survival and stable yields up to salinity levels of 8 dS/m where modern HYVs failed, with average grain yields ranging from 2.5–4.8 tons/ha. Field trials found certain landraces (e.g., Malabati, Patnai) withstood inundation for up to 14 days, maintaining chlorophyll content and antioxidant enzyme activity under stress. The intervention directly reached 1,350 smallholder households, reducing annual crop loss by 48% post-cyclone events. By championing community seed banks and participatory monitoring, this initiative advanced food security, genetic diversity, and climate resilience in a high-risk delta landscape.

THE DISAPPEARING LAND

The final turn of the vise is coastal erosion. The combined force of rising seas, stronger wave action, and the degradation of natural defences like mangrove forests is causing the land itself to disappear. In parts of India's Godavari delta and Bangladesh's coast, entire villages and swathes of farmland have been consumed by the sea. This physical loss of arable land permanently shrinks the resource base for food production, forcing communities to retreat and abandon their ancestral farms.

Agro-ecological Innovations for Coastal Resilience

Salt-Tolerant Rice Varieties

Research institutions such as the International Rice Research Institute (IRRI) and Bangladesh Rice Research Institute (BRRI) have developed varieties like BRRI dhan67 and Swarna-Sub1, which maintain yields under saline and flood-prone conditions (IRRI, 2021).

FARMING ON WATER: SAFE'S FLOATING AGRICULTURE BOOSTS CLIMATE RESILIENCE IN THE INDIAN SUNDARBAN

The South Asian Forum for Environment's float farming initiative in India (2018–2025) empowered flood-affected and marginalized communities to construct floating hydroponic rafts from locally available biomass. Each raft produced 130–170 kg of vegetables and 150–200 kg of fish per season (every three months), raising household earnings by 65–70% and improving food security during monsoon floods or lockdowns. More than 2,200 households in 12 Sundarban villages benefited, with solar-powered micro-irrigation and aquaculture integration enhancing resilience. The intervention reduced crop losses to less than 10% during super-cyclones and built adaptive capacities for climate-vulnerable women and smallholders.

Integrated Rice–Fish Farming

In coastal Odisha and Bangladesh, Ahmed and colleagues (2019) demonstrated through field trials that integrating rice and fish farming can double household protein intake and reduce pesticide use by nearly 30%, while enhancing ecosystem health and food security (Ahmed *et al.*, 2019).

Agroforestry and Silvo-fisheries

Mangrove-based aquaculture (‘silvo-fisheries’) combines shrimp cultivation with mangrove conservation. In Vietnam, this has improved yields by 20% while protecting coasts (IFAD, 2020) a model increasingly relevant for South Asia.

Climate Change Impacts on Coastal Agriculture

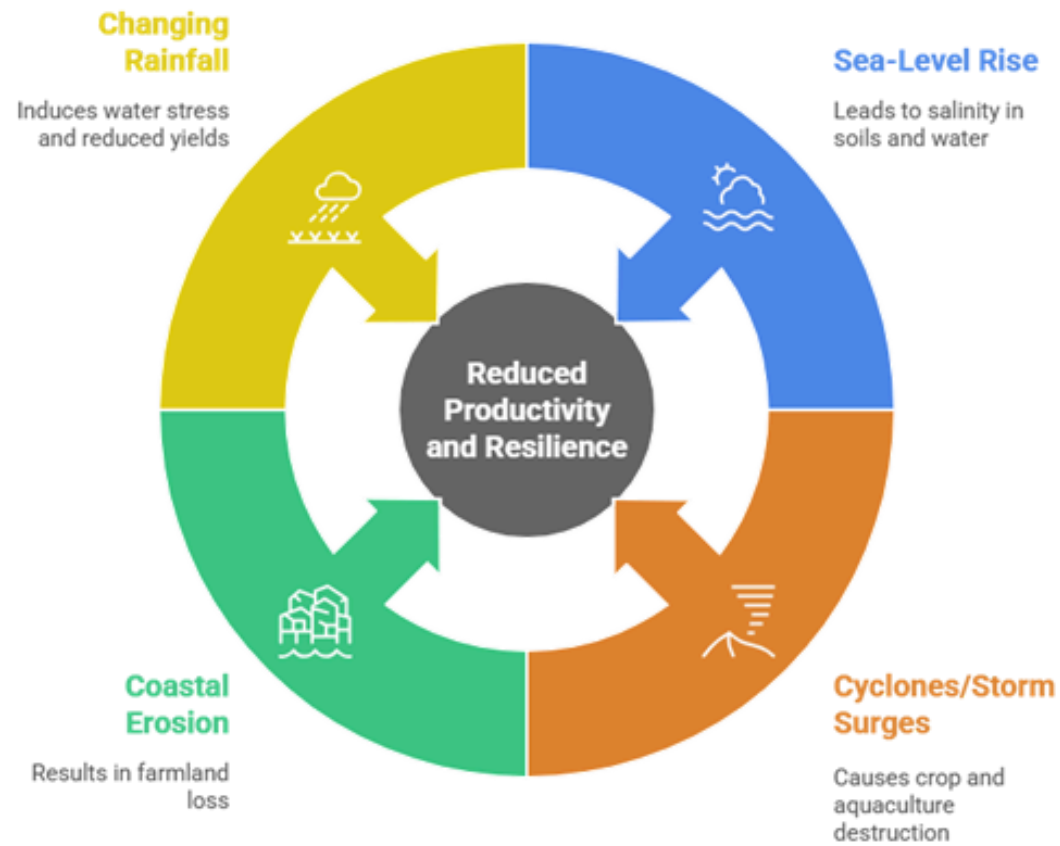


Figure 2 ‘How climate change attacks coastal food systems’ (salinity, erosion, storms, soil loss)

MANGROVES AND AQUACULTURE IN HARMONY: NATURE-BASED REVOLUTION IN THE SUNDARBAN

Integrated mangrove aquaculture (IMA) in the Indian and Bangladesh Sundarban has transformed smallholder shrimp farming by embedding mangrove seedlings directly in aquaculture ponds. On over 50 model farms, this approach increased shrimp yields by up to 35% and improved finfish diversity, while cutting disease incidence by 22% and stabilizing pond banks. Mangrove roots enhanced nutrient cycling and water quality, enabling natural feed for aquatic stocks. In Bangladesh, the Sundarbans Eco Village restored 150 hectares of mangroves, training 250 farm families including women’s cooperatives in IMA practices. Pilot farms reported higher income security and resilience to cyclones, with local biodiversity indices improving alongside aquaculture output. This pioneering, community-based strategy now serves as a scalable blueprint for climate-adaptive livelihoods and ecosystem restoration in coastal South Asia.

AQUAPONIC SYNERGY: BOOSTING RICE AND FISH YIELD IN BATTICALOA, SRI LANKA

In Batticaloa, Sri Lanka, farmers have pioneered integrating aquaponics with traditional paddy cultivation, producing rice and fish concurrently while reducing freshwater use by up to 40% (FAO, 2021). Early trials yielded a 15% increase in combined food output per hectare. Fish species cultivated alongside rice improve nutrient cycling, enhancing soil fertility and suppressing pests naturally. This synergistic system optimizes water resource efficiency in a monsoon-dependent region prone to freshwater scarcity. Capacity building through local extension services and participatory Farmer Field Schools supports upscaling and sustainability. The intervention strengthens household food security and diversifies income streams, providing a model for climate-resilient agriculture in tropical deltaic regions with water constraints.

Socio-economic Dimensions

Vulnerable Communities

Coastal agriculture is often the last safety net for the poor. Women and marginalized groups are disproportionately affected: for example, in Bangladesh, 60% of women farmers report losing livelihoods due to salinity intrusion (ADB, 2020).

Livelihood Diversification Crab Fattening (Bangladesh):

Women’s cooperatives in Khulna earn up to US\$1,200 per season, triple their earlier incomes (Islam & Shamsuddoha, 2018).

Seaweed Farming (India & Sri Lanka): In Tamil Nadu and Palk Bay, seaweed cultivation requires minimal inputs and provides coastal women with a steady source of cash income.

Coastal farming innovations range from vulnerable to resilient.



Figure 3 ‘Traditional paddy vs. climate-smart coastal farming

Technology and Policy Responses

Technological Tools Remote

- **Sensing & GIS:** Salinity intrusion mapping by ICRISAT and ICAR in India helps identify vulnerable villages.
- **Early Warning Systems:** Bangladesh's cyclone preparedness program, integrating SMS alerts and shelters, has saved thousands of lives (UNDP, 2021).

Policy Responses

- India: National Mission on Sustainable Agriculture promotes climate-resilient crops and practices.
- Bangladesh: Delta Plan 2100 integrates coastal food security into long-term planning.
- Sri Lanka: National Adaptation Plan focuses on drought- and salinity-tolerant paddy research.

Regional Cooperation

While SAARC and BIMSTEC have frameworks on agriculture, regional coordination remains weak, especially in coastal climate adaptation (SAARC, 2020).

Coastal livelihood diversification ranges from single to dual crops

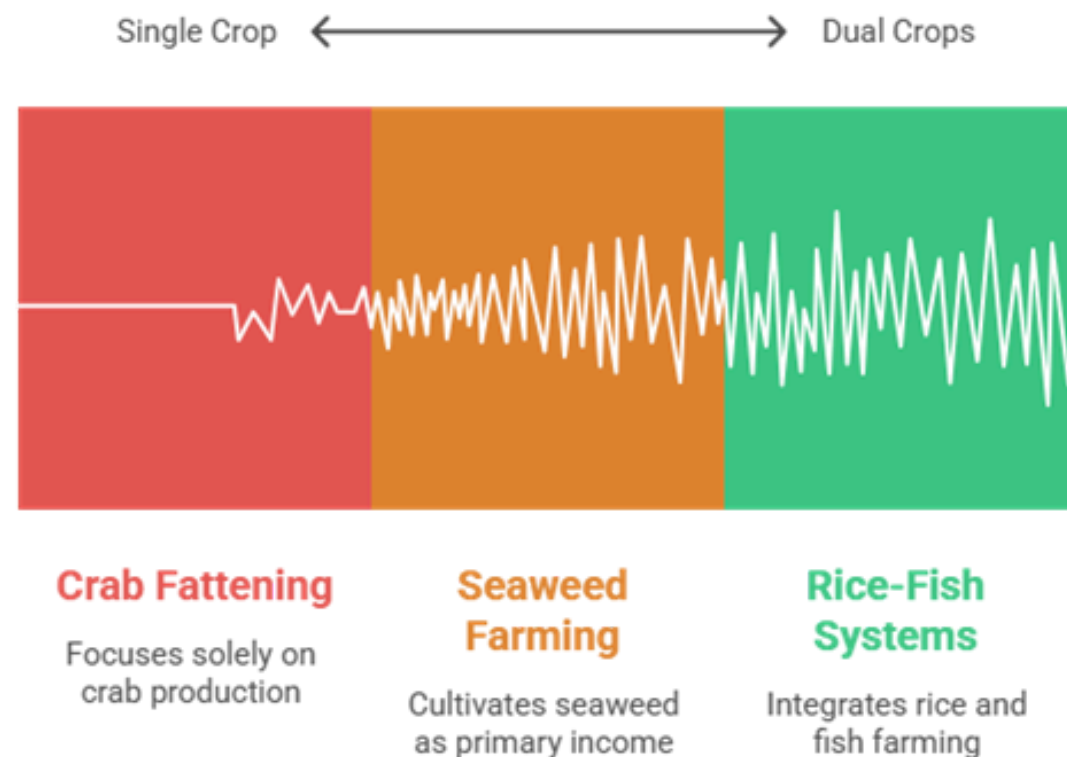


Figure 4 From farm to future: Livelihood diversification in coastal South Asia

Looking Forward: Pathways to Resilient Coastal Food Systems

The future of food security in South Asia's coastal belts depends on integrating climate science, community knowledge, and regional cooperation. Key strategies include:

- Scaling up salt-tolerant and flood-tolerant crops.
- Promoting nature-based solutions like mangrove restoration.
- Supporting community-based adaptation with gender-sensitive approaches.
- Enhancing regional data-sharing and joint risk management.

Coastal agriculture is not merely a livelihood, it is South Asia's frontline defense for food security in an era of climate uncertainty.

Conclusion: From the Frontline to the Forefront

The coastal communities of South Asia are living in a real-time climate laboratory. The challenges they face today are a stark preview of what many other coastal regions around the world will face tomorrow.

The solutions they are pioneering from floating farms and salt-proof seeds to integrated bioshields are therefore not just local adaptations. They are globally significant innovations that offer a powerful message of hope. By supporting these communities with forward-thinking policies, investing in scientific research, and empowering local knowledge, we can help turn a region on the edge of a crisis into a global leader at the forefront of building a resilient, food-secure future for all.



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Policy & Technology Landscape

Country	Policy Initiative	Key Focus	Gaps
 India	NMSA	Climate-resilient crops	Limited coastal focus
 Bangladesh	Delta Plan 2100	Salinity management, water governance	Financing
 Sri Lanka	Adaptation Plan	Salinity-tolerant paddy R&D	Implementation

Figure 5 Policy comparison table: ‘Who is Doing What in Coastal Food Resilience?’



Figure 6 Resilience wheel: ‘Integrated solutions for coastal food security’

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Introduction

Agrobiodiversity the spectrum of cultivated plants, livestock, and associated microorganisms within agricultural landscapes is the bedrock of both food security and ecological resilience (*Singh et al., 2022; Khan et al., 2022*). It buffers communities against environmental shocks, enriches nutritional quality, and preserves adaptive genetic reservoirs critical for sustainable farming and climate resilience (*Jones et al., 2021; Ruiz-González & Vicente, 2023*). Yet, the global drive toward agricultural homogenization has led to the dramatic loss of traditional varieties and narrowing of food baskets, raising concerns for nutrition, pest resistance, and ecosystem services (*Hailu, 2025; Bharucha & Pretty, 2010*).

West Bengal and Odisha stand out as distinctive agrobiodiversity hotspots. The fertile sundarban, coastal plains, and highly varied topographies of these states historically supported thousands of indigenous rice varieties over 5,000 in West Bengal alone, and similarly diverse landraces in Odisha adapted to salinity, drought, and submergence (*Pal, 2016; De & Dey, 2021; Ghosh et al., 2022*).

This spectrum extends beyond rice to encompass pulses, millets, oilseeds, and a range of wild and underutilized crops, with tribal communities acting as stewards of this genetic wealth (*Nayak & Kumar, 2019; Tamang et al., 2021*). Additionally, traditional livestock such as the Motu and Birnjharpuri cattle, and aquatic biodiversity comprising over 345 freshwater fish species, contribute to food and livelihood security, especially among marginalized rural groups (*Das & Das, 2016; Chanda & Jana, 2021*).

However, these systems are increasingly threatened by demographic pressures, land fragmentation, rural outmigration, and the Green Revolution's spread of high-yielding varieties. Nearly 79% of West Bengal's folk rice landraces have vanished from fields in recent decades, while market-oriented monocultures erode risk-buffering crop mosaics (*Panda et al., 2013; Naik et al., 2025*).

These changes have amplified vulnerability to climatic extremes and undermined the food and nutritional security of already at-risk populations, as manifested in persistent anemia and undernutrition among children and women (*Biswas et al., 2023; Das et al., 2023*). The agrobiodiversity-food security nexus in West Bengal and Odisha thus embodies both a cautionary tale and an opportunity.

Indicators of genetic erosion, livelihood vulnerability, and nutritional disparity are juxtaposed with examples of community-driven conservation, globally recognized landrace preservation sites, and dynamic, traditional food systems that deliver dietary diversity and resilience (*Sethi et al., 2025; Mishra et al., 2018*). This paper explores the complex linkages between agrobiodiversity and food security across this mosaic, critically assessing the region's current status, identifying key challenges, and envisioning future pathways for sustainable, nutrition-sensitive agriculture amid accelerating environmental change.

Agrobiodiversity and Food Security Nexus in West Bengal and Odisha

CURRENT STATUS, CHALLENGES, AND FUTURE PROSPECTS

Author: Bhaskar Deb Bhattacharya, PFRI

Img: Communication Department, PFRI

Agrobiodiversity Status

Crop Diversity

West Bengal historically cultivated over 5,000 indigenous rice varieties, with the entire Bengal region once growing 10,000 varieties (Pal, 2016; De & Dey, 2021). Traditional varieties like Gobindabhog and Tulaippanji remain culturally significant (Chatterjee & Samanta, 2022), while Odisha maintains salt-tolerant and stress-resistant landraces (Ghosh *et al.*, 2022). However, Green Revolution high-yielding varieties (HYVs) have caused significant genetic erosion, with nearly 79% of folk rice landraces documented in the late 1990s no longer cultivated (Panda *et al.*, 2013).

Beyond rice, both states cultivate diverse cereals (wheat, maize, millets), pulses (lentil, black gram, pigeon pea), and oilseeds (mustard, groundnut, sesame) adapted to varied agroecological zones (Nayak & Kumar, 2019). Horticultural diversity includes indigenous fruits like kendu (*Diospyros melanoxylon*) and extensive vegetable varieties supporting smallholder livelihoods (Roy *et al.*, 2015). Wild relatives and underutilized crops provide genetic resources and supplement diets, particularly among tribal communities (Tamang *et al.*, 2021).

Livestock and Aquatic Diversity

Indigenous cattle breeds like Motu and Birnjharpuri in Odisha are valued for drought tolerance and milk production, while the Manda buffalo adapts well to local conditions (Das & Das, 2016). Traditional poultry, goats, and sheep contribute significantly to food security and rural livelihoods. Both states possess rich freshwater fish diversity with over 345 species, supporting major aquaculture industries (Chanda & Jana, 2021).

Agroecological Systems

Traditional mixed cropping, intercropping, and agroforestry systems maintain biodiversity while enhancing resilience (Halder, 2021). Tribal regions practice shifting cultivation and millet-based systems, serving as repositories of agrobiodiversity. Wetland systems support multiple uses including rice cultivation, fishing, and fodder collection, though increasingly threatened by conversion to monocultures.

Food Security Landscape

Nutritional Status

Both states have improved nutritional outcomes but face persistent challenges. Child stunting in Odisha declined from 48.2% (NFHS-1) to 31.0% (NFHS-5), while anemia remains high: 64.2% in Odisha and 69.0% in West Bengal. Women's low BMI prevalence in Odisha decreased from 48.0% to 20.8%, though disparities persist among marginalized groups with higher underweight prevalence among Scheduled Tribe women (23.63%) compared to Scheduled Caste women (15.72%) in West Bengal (Biswas *et al.*, 2023).

Traditional Food Systems & Markets

Traditional diets center on rice, pulses, and diverse vegetables with significant wild food contributions (Civitello, 2011). Tribal communities like the Oraon maintain dietary diversity through locally sourced proteins and minimally processed foods (Bisai *et al.*, 2023). Seasonal food availability shapes both diets and cultural practices, with specific crops harvested throughout the year. Local markets and weekly haats facilitate produce distribution, while government schemes like PMFME promote value chain development (KNN India, 2025). However, farmers face challenges accessing formal markets due to infrastructure barriers (Mandal *et al.*, 2021).

Agrobiodiversity-Food Security Linkages

Nutritional Diversity and Risk Management

Agrobiodiversity underpins dietary diversity, particularly in rural areas. Koraput's Globally Important Agricultural Heritage System exemplifies how diverse landraces ensure year-round nutrient availability (Mishra *et al.*, 2018). Traditional varieties often contain higher micronutrients than HYVs, providing essential iron, zinc, and vitamins critical for combating hidden hunger (Gupta, 2005). However, HYV adoption has sometimes reduced micronutrient content and increased soil deficiencies (Nishad *et al.*, 2020).

Crop diversity enables risk spreading and climate adaptation, with traditional varieties adapted to local stressors like salinity and submergence (Maiti *et al.*, 2014). Many landraces possess inherent pest and disease resistance, reducing chemical input dependence (Dar *et al.*, 2006). Traditional knowledge systems, particularly women's expertise in crop selection and processing, are vital for maintaining both agrobiodiversity and food security (Panda *et al.*, 2013).

Major Challenges

Genetic Erosion and Climate Change

Rapid loss of traditional varieties threatens genetic resources, driven by market pressures, changing consumption patterns, and inadequate policy support (Nishad *et al.*, 2020). Rising temperatures, erratic rainfall, and extreme events increasingly threaten crop yields, while sea-level rise poses major risks to coastal agriculture through increased salinity and waterlogging (Sethi *et al.*, 2025).

Socioeconomic and Policy Pressures

Land fragmentation, urbanization, and rural outmigration undermine traditional farming systems. Market-driven monocultures and price volatility incentivize HYV cultivation over traditional varieties. Conservation policies remain limited with insufficient emphasis on in-situ conservation, while extension services lack capacity to promote agrobiodiversity, particularly in remote areas.

Conservation and Future Prospects

Conservation efforts combine ex-situ strategies through gene banks and community seed banks like the Vrihi Seed Bank, with in-situ conservation via farmer-led initiatives in Koraput and Rayagada (Varshney & Chauhan, 2025). Policy frameworks including the Protection of Plant Varieties and Farmers' Rights Act and state programs like Odisha's Shree Anna Abhiyan provide institutional support. NGOs facilitate grassroots conservation, capacity building, and knowledge preservation.

Future opportunities include digital platform integration, precision agriculture, and climate-smart technologies enhancing productivity and resilience. Growing niche markets for traditional varieties supported by organic certifications and Geographical Indication tagging offer new income avenues. Policy innovations incorporating benefit-sharing mechanisms and intellectual property protection for farmers are essential for recognizing local conservation efforts.

Conclusion

Agrobiodiversity serves as the linchpin of food security, environmental resilience, and cultural identity in West Bengal and Odisha. The region's historical legacy, marked by thousands of indigenous rice varieties, robust landrace adaptation to biotic and abiotic stressors, and regionally unique livestock and aquatic resources, has underpinned not only productivity but the nutritional diversity essential for combating hidden hunger and micronutrient deficiencies. Scientific literature underscores that diverse farming systems enhance ecosystem services such as soil fertility, pest regulation, and climate buffering, providing empirical evidence for the resilience observed in traditional agricultural landscapes.

Yet, current trajectories demonstrate a critical tipping point. High-yielding variety (HYV) monocultures, land fragmentation, climate change, and market pressures have accelerated genetic erosion, particularly among rice landraces, with a documented 79% decline in folk varieties over recent decades. The accompanying reduction in nutritional, ecological, and economic buffering capacity heightens the risk profile for vulnerable communities, including tribal and marginalized social groups, as reflected in persistent child anemia and underweight prevalence.

Conservation and sustainable use must thus rest on a multipronged strategy.

This includes Strengthening In Situ **Conservation:** Farmer-led initiatives and community seed banks (e.g., Vrihi Seed Bank, Koraput heritage systems) are critical for maintaining adaptive landraces and traditional knowledge.

Policy Innovation: Legal instruments like the Protection of Plant Varieties and Farmers' Rights Act must be reinforced with practical support: extension services, benefit-sharing schemes, GI certification, digital record-keeping, to empower cultivators as active stewards and beneficiaries.

Integration of Modern Technologies: Climate-smart and precision agriculture, digital value chains, and molecular breeding can help recover and propagate resilient varieties, optimize resource use, and recover productivity losses without eroding genetic diversity.

Promoting Market Incentives

Niche and premium markets for landraces, supported by organic, GI, and biodiversity-friendly labeling, can create economic incentives aligned with conservation and rural development goals.

Addressing Socioeconomic Determinants

Tackling land fragmentation, providing infrastructure and market access, and ensuring social safety nets are essential to remove barriers that force farmers toward monocultures and away from diverse, risk-spreading systems.

Ultimately, the agrobiodiversity-food security nexus in West Bengal and Odisha is not solely a scientific or policy challenge but a societal mandate to honor and harness ecological heritage in the face of rapid global change. Collective action, from grassroots communities to research and policy institutions remains imperative to turn the tide against genetic erosion and secure diversified, nutritious, and resilient food systems for future generations.

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Cultivating Resilience: Indigenous Communities as Guardians of Agricultural Heritage

Focus Area: Linking agrobiodiversity with nutritional security and local food culture

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Introduction

Preservation of agrobiodiversity has emerged as a primary concern of conservationists in recent years, supported by growing evidence of its crucial role in ensuring food security in the current climate milieu (*Das and Das, 2020*). According to the Food and Agriculture Organization (FAO), agrobiodiversity may be defined as the product of the interplay between nature, genetic resources, and diverse cultural practices (*FAO, 1999*). Notably, genetically diverse crops and livestock populations enhance systemic tolerance to climatic transformations as well as resistance to pathogens, thereby boosting agroecosystem resilience and stabilising yields to meet global food demands (*CBD, 2008*). Moreover, agrobiodiversity contributes to balanced nutrition and dietary diversity, vital for sustaining human health. Local food cultures, which have evolved over centuries symbiotically with regional agrobiodiversity and natural processes, assume paramount importance in this context. They provide greater nutritional diversity and ecological sustainability than food systems dependent on commercial monocultures. Being deeply rooted in the cultural heritage of indigenous communities and intergenerational in nature, these local food systems enable the conservation of traditional knowledge. Furthermore, they are less susceptible to disruptions in global supply chains and reduce community dependency on external sources of food, ultimately fostering food sovereignty (*Banerjee et al., 2024; Emmanuel, 2024*).

Unfortunately, despite the globally recognised importance of agrobiodiversity and traditional food systems, significant challenges are encountered in the preservation of both. Conservation efforts face substantial institutional as well as economic barriers, such as limited funding for traditional agricultural efforts, inadequate policy frameworks biased towards high-yielding varieties, and inefficient market support systems for traditional farming products. Additionally, technical and knowledge-based challenges like the loss of traditional ecological knowledge due to reduced intergenerational transmission, lack of specialised extension services for diversified cropping systems, and the complexity of synchronizing multiple crops in traditional rotation systems, persist, causing further problems (*Rodriguez et al., 2021*).

Notwithstanding these formidable obstacles, indigenous communities across the world continue to demonstrate considerable resilience in preserving agrobiodiversity and strengthening local food cultures through innovative natural methods. For example, in the Potato Park of Peru, which encompasses more than 15000 hectares of land in Cusco, six indigenous Quechua communities jointly conserve wild as well as cultivated potatoes of approximately 1365 varieties for both local consumption and sale (*Terry, 2021*). Likewise, in Ecuador, Kichwa communities maintain women-led agroforestry systems, applying traditional ecological knowledge for forest conservation while providing food and medicinal resources for their families (*Trias, 2024*).

In India, a nation with an extraordinary agricultural heritage, covering diverse agro-climatic zones, the conservation of agrobiodiversity through traditional food cultures represents a vital pathway to sustainable nutritional security. Indigenous communities across the country have developed sophisticated food systems that not only preserve genetic diversity but also ensure balanced nutrition through locally adapted crops and traditional dietary practices. For instance, the tribal farmers of Odisha, particularly women farmers from Koraput, protect vital landraces of rice, pulses, millets, oilseeds, and edible wild flowers, resulting in its designation as a 'Globally Important Agricultural Heritage Site' by the Food and Agricultural Organization (FAO).

Tribal farmers like the widely known Ms. Raimati Ghiuria, who has responsibly protected more than 70 and 30 landraces of paddy and millets, respectively, for more than a decade, act as custodians of genetic diversity, employing traditional knowledge systems to optimize crop diversity for maintaining nutritional requirements. Incidentally, the state government of Odisha has extended considerable support in this regard, registering more than 900 agricultural varieties under the Protection of Plant Varieties and Farmers' Rights Authority (PPVFRA). Furthermore, landrace mapping activities have been conducted across over 500 remotely located villages through initiatives such as the 'Shree Anna Abhiyan' and the 'Special Programme for Promoting Integrated Farming' in tribal areas (Padhee., 2025).

Also, in West Bengal, the indigenous tribes of Dakshin Dinajpur preserve comprehensive knowledge regarding 63 wild edible species (Madhuca longifolia, Marsilea vestita, Colocasia esculenta, Termitomyces heimii, etc.) spanning 36 botanical families, through extensive documentation, including 1603 usage citations. Notably, these plants offer crucial dietary supplements and enhance local food security (Chowdhury et al., 2024).

Similarly, local farmers in the Sundarban region of West Bengal conserve indigenous landraces of paddy, supported by local non-governmental organizations. Moreover, the Oraon and Sadan tribes of Jharkhand maintain advanced seed preservation techniques wherein individual households meticulously cultivate their preferred landraces, gathering seeds from the central parts of chosen fields, with women assuming vital responsibilities in the process of seed selection. Research indicates that 146 traditional rice cultivars are grown by these communities, showcasing exceptional genetic diversity preservation (Dasegowda et al., 2023). Further east, traditional rice preservation initiatives in Assam focus on distinct types such as Joha (fragrant rice), Chokowa (tender rice), Bora (sticky rice), and Bao (crimson rice) as these possess considerable commercial potential for generating supplementary revenue alongside preserving cultural importance during traditional celebrations and ritual occasions (Roj, 2020).

In Manipur, traditional shifting cultivation incorporates 32 different crop species and four indigenous livestock breeds, along with a number of landraces that contribute to nutritional security and safeguard local culinary heritage.

Additionally, the inclusion of wild edibles sourced from forests and fallow areas enhances customary diets and strengthens indigenous food cultures (Pandey et al., 2024). Also, tribal communities of Mizoram farm a mix of crops like rice, maize, millet, sesame, and various vegetables on shared plots through traditional shifting cultivation. Their age-old rotational methods provide adequate time for forests to regenerate and help in sustaining the local agrobiodiversity, which contributes to long-term food security (Amrutha et al., 2024).

The remarkable agrobiodiversity documented across these Indian communities demonstrates that the preservation of genetic diversity is fundamentally linked to the vitality of local food cultures and traditional customs. When these food traditions are actively practiced and celebrated, especially during festivals and ceremonies, the crops linked to such practices naturally find sustained spaces in the local agricultural landscape (Padhee, 2025). For example, the continued cultivation of Bao rice in Assam and specific millet types in Manipur can be attributed largely to their cultural significance in traditional celebrations and their value in customary diets (Amrutha et al., 2024; Pandey et al., 2024).

As communities and local governments consistently validate and promote indigenous food systems, farmers are motivated to maintain crop diversity for both nutritional and cultural needs. Conversely, when local food cultures decline, several agricultural species often vanish from cultivation, resulting in genetic erosion and reduced nutritional diversity (Padhee, 2025).

However, these traditional agrobiodiversity conservation systems face increasing pressures from rapid urbanisation, impacts of climate change, and the migration of youth from rural areas. All these factors threaten the intergenerational transmission of indigenous knowledge and practices. In order to ensure the sustainability of these remarkable conservation efforts, integrated policy frameworks must be developed that recognize traditional crops not merely as genetic resources, but as viable economic opportunities (Zimmerer et al., 2021). The commercial potential demonstrated by indigenous crops in Assam and Odisha suggests that traditional agrobiodiversity can engender substantial livelihood opportunities while preserving genetic diversity if value chain development, market linkages, and branding support are adequately established.

Consequently, future research ought to prioritise the documentation of nutritional profiles of traditional agrobiodiversity, the development of participatory plant breeding programs that integrate indigenous knowledge with modern techniques, and the creation of economic incentives to encourage young farmers to participate in traditional agriculture. Policy interventions must focus on establishing Farmer Producer Organisations for traditional crops, integrating indigenous crops into public distribution systems, and promoting agritourism initiatives that highlight traditional farming practices. The rich agrobiodiversity heritage of India can be safeguarded for future generations, while continuing to ensure nutritional security and cultural identity for indigenous communities, only through such comprehensive strategies (Rana et al., 2022).

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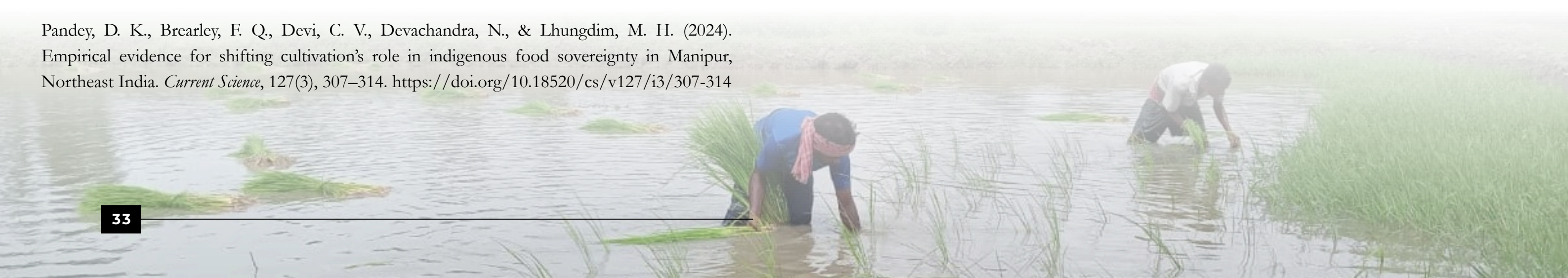
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Role of High-Quality Seeds in Climate Smart Agriculture

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Introduction

Climate-smart agriculture (CSA) is an integrated approach designed to address the challenges posed by climate change to global agriculture (Dar *et al.*, 2024). It aims to enhance agricultural productivity, improve resilience to climate change, and reduce greenhouse gas emissions, thereby ensuring food security and sustainability. Key practices like conservation agriculture and agroforestry improve soil health and water retention, reducing vulnerability to droughts and floods (Safdar *et al.*, 2024). Technologies such as precision farming and biotechnology optimize resource use (Mandal & Mandal, 2024), while drought-tolerant crop varieties ensure stable yields (Safdar *et al.*, 2024).

Quality Seeds and Climate-Smart Agriculture

High-quality seeds play a crucial role in climate-smart agriculture by enhancing productivity and resilience to climate change (Zossou et al., 2021; Shahbaz et al., 2022; Shelar et al., 2021; Chirag & Mohammad, 2023; Hussain et al., 2024). CSA integrates climate change adaptation and mitigation with environmental, social, and economic sustainability (Zossou et al., 2021). High-quality seeds contribute to CSA through:

- **Increased Productivity:** Quality seeds can enhance grain yield by more than 20% (Maity et al., 2023). Quality seeds should have high germination and vigor, acceptable genetic and physical purity, be free of seed-borne diseases and insects, and have low moisture content, ensuring vigorous germination, rapid emergence, and robust growth (Maity et al., 2023).
- **Climate Resilience:** Access to stress-tolerant varieties through improved seed systems is an important feature of CSA (Wassmann et al., 2022). Climate-resilient seeds are essential for food security, particularly in light of changing climatic conditions (Shelar et al., 2021). Climate-smart crop production relies on superior seeds and sowing materials of well-adapted breeding varieties (Hussain et al., 2024).
- **Community Seed Banks (CSBs):** CSBs help local communities regain control over seeds, including neglected and underused crop species, while fostering collaboration with plant breeders and research institutes. CSBs contribute to climate change adaptation by increasing availability and access to diverse, locally adapted crops and varieties (Shilomboleli et al., 2023).

Advances in Seed Technologies for Climate Smart Agriculture

Seed Priming

Seed priming is a pre-sowing treatment involving controlled hydration to initiate early germination stages without radicle protrusion, enhancing germination speed and uniformity, especially under stress (Shelar et al., 2021; Devika et al., 2021). Benefits include enhanced germination under adverse conditions, improved crop performance, increased yield potential, and protection against biotic and abiotic stresses (Devika et al., 2021). It improves drought tolerance in cereals and legumes, promoting antioxidant response and osmotic regulation (Balestrazzi et al., 2024).

Techniques include hydropriming, halopriming, osmopriming, solid matrix priming, biopriming, and magnetopriming. Seed priming with salicylic acid alleviates abiotic stress by stimulating germination hormones and inhibiting dormancy hormones (Maity et al., 2023).

Nano-priming

This emerging technology combines seed priming with nanotechnology to improve seed germination, seedling establishment, and plant lifecycle (Singh et al., 2021; Do Espirito Santo Pereira et al., 2021). Nano-priming modulates biochemical pathways, balances reactive oxygen species, and enhances stress and disease resistance, reducing the need for pesticides and fertilizers (Do Espirito Santo Pereira et al., 2021; ÇİĞ et al., 2025). Machine learning can predict germination, vigor, and yield of nanoprimered seeds (Yadav & Mathur, 2024).

Seed Coating

Seed coating involves applying a protective layer to improve handling, visibility during planting, and to supply nutrients, pesticides, or growth-promoting substances (Pathania et al., 2024; Chirag & Mohammad, 2023). Benefits include improved germination phases, advanced phenological events, enhanced physio-morphological attributes, and restored seed efficacy (Javed et al., 2022). It protects against pests and fungal strains, provides nutrients, enhances water retention, and improves seed size for precision planting (Javed et al., 2022).

Types include film coating (enhances germination and eliminates dust-off), pelleting (modifies seed shape and size for better metering and plantability), and encrusting (more economical than pelleting) (Ceritoğlu *et al.*, 2022). Seed coating with Plant Growth Promoting Bacteria (PGPB) is effective for sustainable agriculture, enhancing nutrient uptake and protecting against biotic and abiotic stresses (Ceritoğlu *et al.*, 2022). Nanotechnology in seed coating through nano-encapsulation of fertilizers and pesticides transforms seed management, protection, and supervision (Pathania *et al.*, 2024).

Development of Stress-Tolerant Seed Varieties

Salinity Stress Tolerance

Salinity adversely affects seed germination, seedling establishment, plant growth, and development. Cereals are particularly sensitive to salinity during germination and early seedling phases (Kaur *et al.*, 2022). Genetic improvement is an effective measure for alleviating salt stress (Zhang *et al.*, 2024). Key strategies include:

- **QTLs and Gene Mapping:** Using quantitative trait locus (QTL) mapping is effective for cultivar improvement and can quicken development of tolerant cultivars. Salt tolerance is a polygenic trait controlled by several QTLs (Zhang *et al.*, 2024).
- **Molecular Markers:** Marker-assisted selection (MAS) can enhance salt tolerance in crops (Zhang *et al.*, 2024).
- **Genetic Engineering:** Biotechnological and genetic techniques, including transgenic and gene engineering, can improve cultivation methods and enhance salt tolerance in crops (Zhang *et al.*, 2024).
- **Seed Priming Applications:** Different priming types provide specific benefits: hydropriming in paddy enhanced resistance against CO₂ stress, osmopriming with CaCl₂ in wheat provided drought resistance, hormonal priming with cytokinins imparted salt stress tolerance in wheat, and biopriming with *Pseudomonas fluorescens* mitigated salt stress in groundnut (Devika *et al.*, 2021).

Flood Tolerance

Developing flood-tolerant seed varieties is crucial for regions prone to recurrent flooding, with potential to significantly increase rice production (Koppa & Amarnath, 2021). The Sub1 (Submergence tolerance 1) QTL has been incorporated into high-yielding rice cultivars using marker-assisted breeding (MAB) (Dar *et al.*, 2021).

The variant Swarna-Sub1 can endure complete flooding for over 15 days and recovers well once water recedes (Koppa & Amarnath, 2021; Dar *et al.*, 2021). Improved Sub1 varieties, including IR 64 Sub1, Swarna Sub1, Ciherang Sub1, Samba Mahsuri Sub1, and BR 11 Sub1, have significantly enhanced yield under stress conditions (Mwakyusa *et al.*, 2023).

Future Perspectives and Stewardship Practices

Smart agriculture uses state-of-the-art crop production technologies. Remote sensing-based crop monitoring and input application, along with disease-pest monitoring using unmanned aerial vehicles, are crucial. Region-specific production and storage recommendations should be advocated for seed growers and local businesses (Maity *et al.*, 2023).

Identifying relevant seed traits is fundamental for managing and selecting seeds in challenging conditions, requiring detailed agronomic and genetic information to characterize valuable traits (Balestrazzi *et al.*, 2024).

Conclusion

Climate-smart agriculture offers a sustainable pathway to enhance food security in an era of climate uncertainty, with quality seeds serving as a cornerstone of this approach. High-quality seeds ensure higher yields, better resilience to climate stresses, and improved economic outcomes for farmers. Advanced seed technologies including priming, coating, and nano-applications provide innovative solutions for stress tolerance. However, the success of CSA depends not only on seed quality but also on supportive policies, farmer education, and holistic ecosystem management. By combining advanced seed technologies with sustainable farming practices, agriculture can become more adaptive, productive, and climate-resilient, ensuring long-term food security for future generations.



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Restoring Roots: Traditional Wisdom and Regenerative Practices for Soil Health in a Changing Climate

Focus Area: Soil health, organic and regenerative practices

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Introduction

Agricultural resilience in India is under threat from an often-overlooked crisis soil degradation. Years of intensive cultivation, synthetic inputs, and monocropping have led to significant losses in soil vitality. Today, nearly 30% of Indian landmass, equivalent to 96 to 120 million hectares, is degraded (*GIZ & CEEW, 2024*). With over half of total available land deficient in Soil Organic Carbon (SOC), it is critical to move from extractive to regenerative practices to sustain productivity and climate resilience.

This crisis is not only a threat to food security but also to the broader environmental health of the subcontinent, where soil acts as the first line of defence against droughts, floods, and nutrient loss. Addressing soil degradation is, therefore, a prerequisite for any long-term strategy on sustainable development.

Core Foundations of Soil Health

Understanding Soil Health

Soil is a living ecosystem, composed of minerals, organic matter, water, air, and billions of microorganisms. It underpins food security, water filtration, carbon storage, and biodiversity (Alori *et al.*, 2017; GIZ & CEEW, 2024). However, deep tillage, chemical fertilizers, and monocultures usually disrupt soil structure and biology. For instance, a mere 1% increase in Soil Organic Matter (SOM) can enhance water retention by up to 75,000 litres per acre (Bhadha *et al.*, 2017).

Healthy soil serves as nature's infrastructure regulating water flow, supporting plant roots, and sustaining microbial communities. Its degradation not only hampers productivity but also undermines resilience to climate extremes.

The Role of Regenerative Agriculture

Regenerative agriculture actively restores soil health through practices such as minimal tillage, cover cropping, composting, agroforestry, and crop rotation. These techniques rebuild organic matter, improve water retention, and reduce chemical dependency. The GIZ–CEEW roadmap emphasizes regenerative farming as vital for India's soil sustainability goals under its Vision 2047 (GIZ & CEEW, 2024).

Field evidence supports this: Andhra Pradesh and Odisha have seen success with Zero Budget Natural Farming (ZBNF), Pre-Monsoon Dry Sowing (PMDS), and organic formulations like Jeevamrut. Despite this, only 1–2% of Indian farmers currently use cover cropping, demonstrating a significant opportunity for scale-up (Gupta *et al.*, 2021).

These regenerative pathways are particularly effective in enhancing soil microflora, fixing atmospheric nitrogen, and enabling carbon sequestration, thus positioning farmers as key climate stewards in India's net-zero mission.

While regenerative agriculture offers science-based methods for restoring degraded soils, these approaches resonate strongly with the wealth of traditional knowledge systems in India. Recognizing the value of indigenous wisdom provides continuity and context, showing how age-old practices can complement and strengthen modern soil health strategies.

Traditional Wisdom and Indigenous Practices

India's farming heritage offers rich soil knowledge. Techniques using cow dung, bio-slurry, and natural amendments nurture microbial life and reduce chemical runoff. Sikkim's full transition to organic farming and Odisha's millet revival exemplifies successful integration of tradition and policy. Initiatives like Meri Maati Abhiyaan also promote community seed banks that support soil-health-compatible, indigenous crop varieties (GIZ & CEEW, 2024).

Such traditions, rooted in centuries of ecological wisdom, can now be revalorized through modern research and scaled through localized policy mechanisms. Indigenous methods provide low-cost, high-impact tools to restore degraded soils while empowering rural communities.

Soil and Climate Co-benefits

Healthy soils sequester carbon effectively, aligning with global goals like the "4 per 1000" initiative that aims to increase SOC by 0.4% annually to offset CO₂ emissions. Techniques such as zero tillage, biochar application, and Direct Seeded Rice (DSR) improve both soil health and water efficiency. DSR alone reduces water use by 18% (Deb *et al.*, 2023).

These synergies between soil regeneration and climate mitigation mean that improving soil quality is not just an agricultural concern—it is a national climate imperative. Enhanced SOC also improves nutrient cycling and reduces nitrous oxide emissions, a potent greenhouse gas.



Img: Communication Department, PFRI

Barriers and Opportunities

Adoption of regenerative methods is hampered by lack of awareness, upfront costs, limited inputs, and weak extension systems. Nonetheless, the GIZ–CEEW roadmap outlines transformative solutions:

- Soil literacy programs in schools and communities
- Institutional partnerships between civil society, research, and government
- Incentives via PM-PRANAM and carbon credit schemes
- Recognition of ‘Soil Stewards’ as local champions

Andhra Pradesh’s Community-Managed Natural Farming Programme (APCNF) exemplifies how grassroots mobilization and decentralized innovation hubs can scale change.

Building a resilient agro-ecosystem depends on democratizing knowledge, enabling access to climate-smart inputs, and securing financial incentives that reward farmers for ecosystem services provided.

Conclusion: A Regenerative Future

Reviving soil health is a national priority. The “Healthy Soil for a Prosperous India” roadmap envisions 131 million hectares under regenerative practices by 2030. To achieve this, soil health indicators must be integrated into budget planning, procurement systems should prioritize local organic produce, and farming must be reimagined as a dignified profession. Through community action, indigenous wisdom, and science-backed policy, India can secure a climate-resilient, regenerative agricultural future beginning from the ground up.

The path ahead lies in aligning tradition with innovation, local realities with global goals, and farmer aspirations with ecosystem integrity. The soil beneath our feet may be silent, but its restoration holds the key to a sustainable tomorrow.

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HEAT-RESILIENT SEED COATINGS: A CLIMATE-SMART APPROACH TO STRESS TOLERANCE

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Lead paragraph

Seed coating technologies have developed into a potent method to enhance seed performance under various challenging environmental circumstances. However, conventional tools often fail when exposed to high temperatures during storage, transportation, and early crop establishment, particularly in arid and semi-arid regions. This communication explores recent advances in the development of heat-resilient seed coating formulations through encompassing thermoprotective agents as a climate-smart approach to safeguard crop productivity in heat-prone agroecologies.

Constraints in maintaining Seed quality under storage and transport-induced stress

Seed quality is very much dependent on a number of biotic and abiotic stresses during storage and transport, particularly in hot and humid climatic regions, or areas with inadequate facilities.

Heat stress can hasten seed aging through the bio-accumulation of reactive oxygen species (ROS), causing cellular membrane damage, metabolic imbalance, and viability as well as vigor loss (Gebeyehu, 2020). Transport-related mechanical stress-such as vibration and compression, further exacerbate deterioration, especially during long-distance handling. Moreover, fluctuation in temperature and humidity may lead to microbial growth or premature and unwanted metabolic activation (Gutiérrez-Pozo et al., 2024). These factors collectively hinder germination and early establishment by disrupting protein stability and enzymatic activity at the early stage of germination. Therefore, stress-mitigating approaches are essential to ensure the physiological integrity of seeds from storage to subsequent sowing.

Thermoprotective Additives for Heat-Resilient Seed Coatings

Trehalose

Trehalose is a non-reducing disaccharide that stabilises proteins and lipid membranes against denaturation under stress by substituting water molecules and forming glass-like structures (Elbein et al., 2003). Trehalose-coated seeds improve membrane integrity, speed of germination, and tolerance to desiccation and heat. In tomato and wheat, trehalose-treated seeds exhibited better root growth under high-temperature conditions (Luo et al., 2022; Yang et al., 2022).

Proline

Proline functions as a compatible solute and osmo-protectant, regulating cellular osmotic equilibrium and scavenging ROS during stress. Its application via seed coating has enhanced seedling emergence and vigor under heat and drought conditions (Ashraf and Foolad, 2007; Kijowska-Oberc et al., 2022). Coated proline also helps with protein stabilization and gene expression linked to heat shock proteins (HSPs), which strengthen thermotolerance.

Chitosan

Chitosan is a naturally occurring polysaccharide derived from chitin that shows biocompatible and film-forming properties. It improves seed water absorption, antioxidant enzyme activity, and disease resistance. Chitosan-coated lentil and groundnut seeds showed elevated germination and enzymatic activity when exposed to stress (Rahman et al., 2013; Vijaykumar et al., 2024). It is an excellent base for polymers since it is biodegradable and compatible with other additives.

Heat Shock Protein (HSP) Inducers

Thermotolerance relies heavily on heat shock proteins, especially HSP70 and HSP101, which assist in protein refolding and prevention against aggregation. Priming agents such as salicylic acid, hydrogen peroxide, and certain natural elicitors can be incorporated into coatings to induce HSPs (Kushawaha et al., 2021). Pre-sowing seed coating with salicylic acid demonstrated upregulation of HSP gene expression in rice and wheat under thermal stress (Sangwan et al., 2022).

Antioxidant Compounds

Tocopherols and ascorbic acid act as ROS scavengers and membrane stabilisers. Their incorporation in seed coating improves cellular resilience to oxidative damage in hot or dry conditions. Studies have shown that antioxidant-treated seeds can maintain viability and higher vigor indices for a longer period, even under stress conditions (Sun et al., 2024).



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Introduction

Agricultural productivity has become vulnerable nowadays as a result of rising global temperatures and increased frequency of extreme heat events, especially in arid and semi-arid zones (Habib-ur-Rahman et al., 2022). Seed germination and early seedling establishment are highly vulnerable stages affected by heat and drought stress, resulting in poor crop stands and yield reduction (Bita and Gerats, 2013). Seed coating is a delivery system that allows precise deposition of bioactive substances at the seed-soil interface to improve stress tolerance and uniform emergence (Pedrini et al., 2017). Despite its potential, conventional seed coatings are often ineffective under high thermal and transport-induced stress, highlighting the need for thermoprotective innovations in formulation.

Nanomaterials as Delivery Carriers

Nanoparticles (NPs), including carbon, zinc, and silica, enhance the slow release and targeted distribution of additives. They facilitate regulated hydration during germination and improve the heat stability of coatings. Nano-enabled coatings with trehalose or chitosan complexes provide synergistic water retention and thermos-protection under field circumstances.

Formulation and Application Strategies

Layered Coating Design

Multi-layered coatings allow a blending of functional components, such as outside layers intended for microbial distribution or mechanical protection and interior ones containing thermos-protectants for stability. Encapsulation of sensitive additives like proline in biodegradable polymers ensures their stability during high-temperature transport.

Coating Integrity and Polymer Selection

Heat-stable seed coatings are often based on polymers like alginate, starch, carboxymethyl cellulose, and polyvinyl alcohol. These materials show low thermal conductivity and prevent desiccation. When applied cautiously, cross-linking chemicals (e.g., glutaraldehyde) can increase adhesion and endurance without preventing germination (Peng *et al.*, 2017).

Application Techniques

The best techniques for uniform layer deposition comprise pan coating and fluidised bed systems, especially for crops with large seeds. Even in filthy transportation settings, electrostatic spraying may be utilised to guarantee adherence and minimise material waste (Javed *et al.*, 2022).

Practical Application and Recent Advances

The application of thermo-resistant seed coating is profoundly purpose-specific. In some cases, seed coatings are highly specific for addressing field-level stresses, while some to manage seed quality, from storage and transport-induced stress.



Table 1. Post-harvest application (Storage and Transport-induced stress)

Crops	Coating Additives	Stress Condition	Key Findings	Reference
Cotton	Carboxin from seed coating formulation	Storage and transport	Germination retained 79% vs. 70% in uncoated seeds after 6 months of storage.	Xiao and Yin, 2019
Groundnut	Arabic gum + benomyl or ascorbic acid	Heat and mechanical stress	Maintain seed viability during storage and transport	Sari <i>et al.</i> , 2013
Sorghum	Polymer + fungicide	Storage stress	Maintain good germination rate and prevent pathogen infection, thus ensuring better viability and vigour over extended periods.	Rao <i>et al.</i> , 2017

Table 2. Pre-Sowing Applications (Field Stress)

Crop	Coating Additives	Stress Condition	Key Findings	Reference
Various	Trehalose + Chitosan	Field stress	Field emergence and seedlings' health were improved	Sen and Das, 2024
Wheat	Trehalose	heat stress (35°C)	Improve heat tolerance by protecting photosystem II and promoting cyclic electron flow.	Luo <i>et al.</i> , 2022
Maize	Chitosan	Heat + Salinity stress	Boosted enzymatic activity and root growth	Jiao <i>et al.</i> , 2024
Cotton	Melatonin	Salt stress	Enhanced germination rate, modulated ABA and GA related genes	Chen <i>et al.</i> , 2021
Tomato	Trehalose	Drought and pathogenic stress	Increased xylem concentrations of jasmonic acid, related oxylipins and drought tolerance	MacIntyre <i>et al.</i> , 2022

Future Prospects

Climate-adaptive approaches are increasingly necessary to safeguard seed quality during logistics, storage, and early plant growth. Advances in materials science and seed physiology can devise the development of next-generation coatings with bio-sensing capabilities, smart-release systems, and adaptive film dynamics. Moreover, future research should focus on optimizing dosages, synergistic formulations, and assessing genotype-specific responses. Regulatory clarity regarding the use of innovative materials, particularly nanoparticles, will be essential for secure commercialisation.

Conclusion

Heat-resilient seed coating formulations incorporating thermoprotective additives offer a promising concept for improving crop establishment through proper maintenance of seed quality under thermal and transport-induced stress. In demanding agroecologies, seed performance can be significantly enhanced by combining the protective effects of trehalose, proline, chitosan, antioxidants, and HSP inducers. These formulations represent a crucial adaptation strategy in the face of climate change and urge further large-scale field testing and commercial implementation.

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Harnessing Water Wisdom in the Indian Sundarban

REVIVING TRADITIONAL RESOURCE MANAGEMENT FOR CLIMATE-RESILIENT FARMING

Author: Soumik Sarkar, Senior Researcher, PFRI

Img: Communication Department, PFRI

Introduction

The Indian Sundarbans, a UNESCO World Heritage site and home to over 4.5 million people, faces the dual pressures of rising sea levels and increased cyclonic activity. Agriculture, especially in Gosaba block, remains the backbone of rural livelihoods, yet it suffers due to increasing salinity, erratic monsoon raining pattern, and the breakdown of natural water retention systems. Historically, the region relied on intricate indigenous water management structures such as bherries (shallow storage ponds), khals (canals), and embanked fields that balanced irrigation, aquaculture, and flood mitigation.

Over time, these systems degraded due to neglect, developmental pressure, and the introduction of mono-cropping. However, recent participatory interventions by local communities, supported by civil society organizations or non-governmental organization and research institutions, have sparked renewed interest in these traditional practices reframed with modern climate resilience thinking.

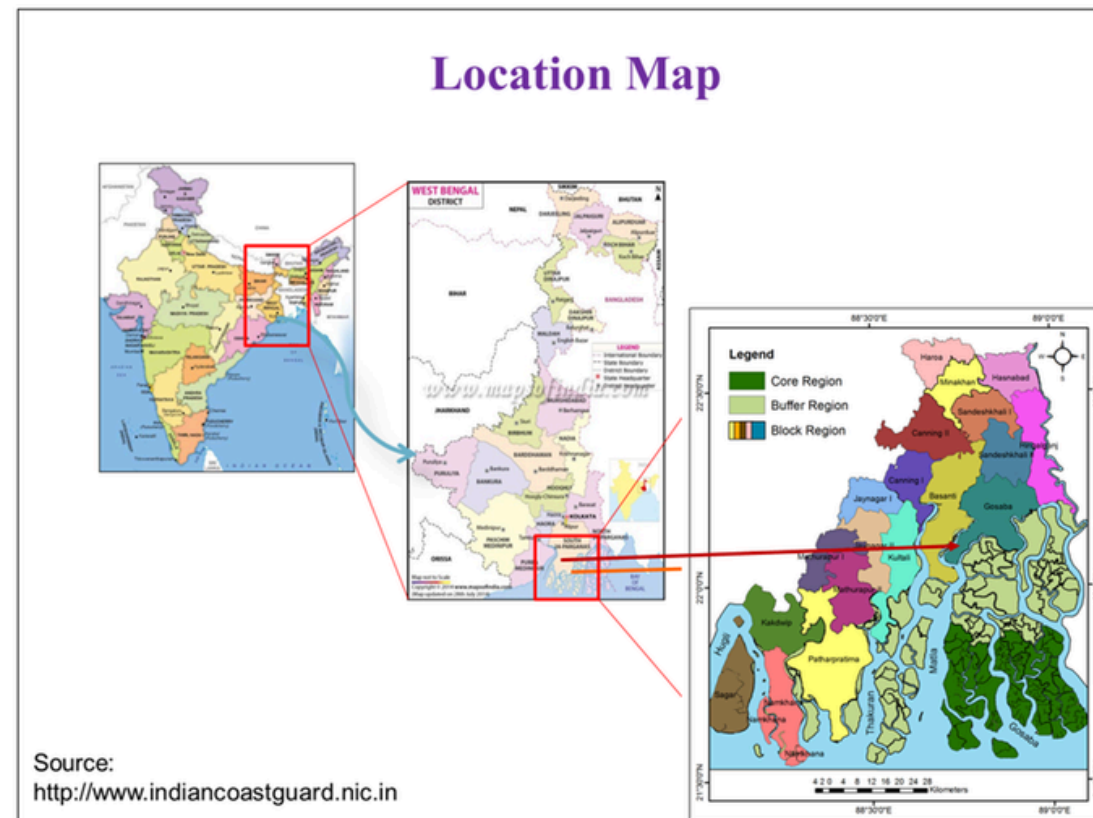


Figure 1: Map showing Gosaba Block in the Indian Sundarbans region, West Bengal.

Community Innovation in Practice

In Gosaba, a women-led collective initiated the rejuvenation of bherries in the villages of Satjelia and Rangabelia. These shallow freshwater ponds, once used seasonally for fish culture and paddy irrigation, were desilted and redesigned to optimise rainwater harvesting and groundwater recharge. The initiative, combined with bund strengthening using local bamboo (*Bambusa tulda*) and vetiver grass (*Chrysopogon zizanioides*), has restored year-round water availability for farming.

One compelling example comes from the farmer-scientist collaboration on “Float Farming” reviving a traditional practice of cultivating vegetables on water hyacinth rafts, now integrated with bio-fertilizers and indigenous rice varieties like Talmugur, known for its saline tolerance and short duration (120–130 days). This innovation allowed marginal farmers to maintain year-round productivity, even during prolonged waterlogging post-cyclones like Amphan and Yaas.



Figure 2: Women-led restoration of traditional ‘bherri’ system in Sundarbans



Environmental and Agricultural Impact

The rehabilitation of traditional water systems has had multiple ripple effects. Localised soil salinity levels have dropped, enabling the cultivation of stress-tolerant paddy and pulses.

The enhanced water retention has improved dry-season productivity and allowed for integrated farming systems combining rice-fish-duck culture. Additionally, biodiversity in the agroscape has rebounded, with a return of native aquatic species and pollinators, thereby supporting ecological balance.

Furthermore, agrobiodiversity has flourished. Over 53 varieties of indigenous paddy including Dudhersar, Kalabhat, and Tulaipanji have been reintroduced via seed exchange program and community seed banks. These varieties are more adaptive to micro-climatic stress and contribute to nutritional diversity and culinary heritage.

Lessons Learned and Path Ahead

The Gosaba experience highlights that traditional water knowledge is not obsolete but an untapped asset. When merged with contemporary science and grassroots mobilisation, it becomes a tool for transformation.

Key lessons include the importance of decentralised planning, youth engagement through school water clubs, and integrating agroecology into Panchayat-level resilience planning. Policy frameworks like MGNREGA and Jal Shakti Abhiyan can support this scaling by investing in community-managed water commons and farmer-led knowledge platforms. Moreover, incentivising eco-certification of such traditional systems could generate green livelihoods and market advantages.

Closing Insight

As climate crises intensify, the Sundarbans' water wisdom rooted in tradition yet adapted for resilience offers a replicable model for Eastern India and other deltaic regions. Strengthening these systems is not just about agricultural survival, but about seeding a future of dignity, sustainability, and ecological justice.

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The Word ‘W’ in Indian Sundarbans

Women, Work, and Well-being

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The Indian Sundarban, a region characterized by its unique mangrove ecosystem and vulnerable coastal communities, is facing immense challenges due to climate change, biodiversity loss, and unsustainable agricultural practices. In response to these challenges, agro ecological transitions where traditional ecological knowledge merges with sustainable farming techniques are gaining momentum. Crucially, women are at the forefront of this transition, actively shaping a more resilient and sustainable agricultural landscape.

Women in the Indian Sundarban play a vital role in shaping the socio-economic and environmental landscape of the region. Despite facing systemic challenges such as limited land rights, financial constraints, and climate vulnerability, they continue to drive sustainable agricultural practices and community-led ecological transformations. Their contributions encompass diverse aspects from small-scale farming and fisheries to entrepreneurship and conservation efforts.

This thematic focus highlights the "W" as a powerful symbol representing Women, Work, and Well-being. It underscores their leadership in agro ecology, their resilience in adapting to environmental changes, and their determination to secure a better future for their families and communities. Women-led collectives, self-help groups, and grassroots movements are fostering sustainable livelihood models, advocating for policy support, and preserving traditional ecological knowledge.

Women-Led Agro Ecological Transformations

In the wake of rising male outmigration and increased human-wildlife conflict in the fragile ecosystems of the Sundarbans, a quiet revolution is taking place led by women. Recent field studies and community-based surveys in the region reveal a compelling trend: women are emerging as the backbone of agro ecological resilience and biodiversity conservation in one of the world's most climate-vulnerable landscapes.

Crisis of Migration and Danger in the Jungle

For decades, men from the Sundarban a vast deltaic region spanning the southern parts of West Bengal have migrated to other Indian states in search of reliable employment. Their departure is driven by declining agricultural returns, saline intrusion from rising sea levels, and lack of local economic opportunities. Meanwhile, some men risk their lives by venturing into the forest illegally to collect fish, honey, or firewood, driven by desperation. Tragically, incidents of fatal tiger attacks are not uncommon. These losses destabilize household structures, leaving women as the primary caregivers and, increasingly, the main economic actors in the community.

Women: Agents of Ecological and Economic Stability

In the Indian Sundarban, women are emerging as key innovators in the transition toward agroecological farming systems in response to socio-environmental challenges such as climate variability, soil salinization, and biodiversity loss. Organized primarily through Self-Help Groups (SHGs), women are adopting ecologically sound practices that integrate sustainability, local knowledge, and resource efficiency. These include multi-cropping systems, bio-composting, vermiculture, and the use of indigenous seed varieties, which collectively enhance soil health, increase agro-biodiversity, and improve resilience to climatic stressors.

Moreover, integrated rice, fish and crab farming models are being implemented to optimize land and water use while maintaining ecological balance. While women have historically contributed to small-scale farming, livestock management, and household food production, their role has often been undervalued. The current shift toward agroecology is not only enhancing ecological outcomes but also positioning women as central actors in sustainable agricultural transformation in this fragile deltaic ecosystem.

"We have learned how to use compost from household waste and grow brinjal, okra, and spinach without chemicals," says Rekha Mondal, a member of a women's collective in Gosaba block. "It not only feeds our children but also helps us sell the surplus in the local market."

Pilot initiatives led by NGOs and supported by government schemes have facilitated the agroecological empowerment of women in the Indian Sundarban by providing training in soil health management, rainwater harvesting, and organic pest management. These interventions enhance local food security, reduce dependence on forest-based resources, and lower reliance on external agricultural inputs thereby alleviating ecological pressure.



ON OPPO
Img: Communication Department, PFRI

Women are increasingly adopting agroforestry systems, integrating fruit trees and medicinal plants into their farming landscapes to promote on-farm biodiversity and ecosystem services. Collective farming models have further strengthened their economic resilience, nutritional outcomes, and social cohesion. Capacity-building programs and financial support from NGOs are enabling women to scale and sustain agroecological practices, thereby reinforcing gender-inclusive climate adaptation and sustainable rural development

From Margins to Leadership

Crucially, these women are not just laborers in the field; they are decision-makers. Women are leading local climate action groups, maintaining seed banks, and mapping biodiversity in their villages. Community-led mangrove restoration initiatives have also witnessed a rise in women participation. For instance, in Kultali, a women's group planted over 1,000 mangrove saplings along eroded riverbanks, providing a natural buffer against storm surges and cyclones.



The Road Ahead: Empowerment through Policy and Practice

Experts urge that women's contributions to agroecology and climate resilience be recognized and institutionalized. Dr. Nandita Bhowmik, an ecologist working in the region, notes, "Women are essential knowledge holders in the Sundarban. Their inclusion in panchayat planning and climate policy is not optional it's critical." Scaling these efforts requires improved access to land rights, microcredit facilities, and market linkages for women farmers. Additionally, education and skill development initiatives tailored for young women can help build a new generation of eco-leaders.

Conclusion

In conclusion, the women of the Sundarbans are not merely adapting to change they are actively shaping it. Their commitment to agroecology, community resilience, and environmental stewardship offers a powerful blueprint for sustainable development. To fully realize this potential, inclusive policies, financial support, and knowledge-sharing must be prioritized. Empowering women through education, skill-building, and decision-making will not only uplift families and communities but also fortify the region against future crises. By recognizing and amplifying the power of "W" women, work, and well-being the Sundarban can chart a course toward a more just, resilient, and ecologically balanced future.

"We may not have big machines," says Rekha with a smile, "but we have strength in our hands and hope in our hearts."



Img: Communication Department, PFRI

Farmers as Co-Creators Strengthening Seed Resilience through Participatory Plant Breeding

Author: Mr. Abhay Das, Finance Officer, PFRI

Introduction

Farmers as Strategic Partners in Agricultural Innovation

Agriculture is undergoing a period of immense challenge and transformation. As climate change accelerates, pests evolve, and weather patterns grow increasingly erratic, the need for resilient, adaptable, and locally-suited seed varieties has become more urgent than ever. Scientific research alone, while vital, cannot fully address these complex issues without the deep, practical insights of the people most directly affected farmers.

Farmers are not just end-users of agricultural technologies; they are custodians of traditional knowledge, stewards of biodiversity, and first responders to environmental stress. Their experiential wisdom, refined over generations, is an invaluable resource. Integrating this knowledge into formal seed development processes can significantly enhance agricultural resilience, particularly through approaches like Participatory Plant Breeding (PPB).

PPB is a collaborative method where farmers, plant breeders, and agricultural scientists work together to develop crop varieties tailored to specific local environments. This method ensures that the seeds developed are not only scientifically sound but also field-tested under real-world conditions, making them more relevant and reliable for smallholder farmers.

The Scientific and Practical Value of Farmer Participation

Traditional plant breeding has often been centralized and top-down, with decisions made in laboratories and research stations far removed from the realities of small farms. This has led to the release of seed varieties that, while technically superior in controlled settings, often underperform in diverse and unpredictable rural environments.

In contrast, PPB engages farmers directly in the selection and evaluation of crop varieties. Farmers host trials on their land, assess performance, provide feedback, and ultimately select seeds that meet their agronomic, environmental, and socio-economic needs. This participatory process offers several practical and strategic advantages:

- **Local Adaptation:** Varieties selected by farmers are more likely to thrive in the specific microclimates, soil types, and pest pressures they regularly face.
- **Higher Adoption Rates:** Farmers are more inclined to adopt and disseminate seeds they have helped to develop and validate.
- **Enhanced Resilience:** Seeds developed through PPB often demonstrate greater tolerance to local climatic stresses, thereby reducing crop failure risk.
- **Empowerment and Ownership:** Farmer involvement fosters a sense of ownership, pride, and autonomy in managing their agricultural systems.

By combining scientific breeding methods with indigenous knowledge, PPB creates a powerful synergy that strengthens both agricultural outcomes and rural empowerment

Economic Benefits Cost-Effective, Scalable, and Sustainable

From an economic standpoint, farmer participation in seed development is not just beneficial it is cost-effective and offers high returns on investment. Conventional seed dissemination models, which exclude farmers from the decision-making process, often face poor adoption rates.

This results in wasted public funds, underutilized technologies, and missed development opportunities.

In contrast, participatory models yield multiple financial advantages:

- **Reduced Input Costs:** Varieties selected through PPB often require fewer external inputs. Drought-resistant seeds, for instance, minimize irrigation costs, while pest-resistant varieties reduce dependence on chemical pesticides.
- **Increased Productivity and Profitability:** By selecting high-performing seeds tailored to their unique conditions, farmers can improve yields and enhance household income.
- **Risk Mitigation:** Localized seeds are more likely to withstand environmental shocks, safeguarding farmers' livelihoods and reducing the need for disaster relief interventions.
- **Seed Enterprise Development:** Farmers engaged in PPB can become local seed producers, establishing decentralized seed systems and rural seed markets that create jobs and circulate income within communities.

A particularly promising outcome of PPB is the emergence of community seed banks and farmer-led seed enterprises. These grassroots initiatives support seed sovereignty, reduce dependence on external suppliers, and ensure timely access to quality seeds during critical planting periods.

Successful Models of Farmer Participation

Across India and globally, numerous successful examples illustrate the transformative power of farmer participation in seed resilience programs. In Odisha and West Bengal, for instance, farmers collaborated with agricultural researchers to identify and refine flood-tolerant rice varieties. These new varieties demonstrated a 20–30% increase in yield compared to traditional ones and significantly reduced crop loss during monsoon flooding. Importantly, they also required fewer chemical inputs, contributing to both cost savings and environmental sustainability.

Similarly, in drought-prone regions of Maharashtra, farmers participated in the selection of improved chickpea and millet varieties. These crops, adapted to water-scarce environments, enabled farmers to maintain productivity during drought years. Within just two growing seasons, many participants reported income gains of up to 40%.

Such programs have often been facilitated with minimal financial inputs primarily focused on training, trial facilitation, and monitoring yet have produced disproportionately large benefits. These cases underscore that farmer participation is not only scientifically sound and socially inclusive but also highly efficient in terms of resource utilization.

Institutional Implications – A Framework for Inclusive Program Planning

To institutionalize and scale the benefits of PPB, NGOs and government agencies must recognize farmer participation not as an optional activity, but as a foundational strategy in agricultural development and climate adaptation programs.

This requires integrating PPB into core program design and budgeting processes. Key recommendations include:

- **Budget Allocations for Farmer Training:** Structured training equips farmers with the skills needed to engage meaningfully in selection trials, seed saving, and evaluation.
- **Support for On-Farm Trials:** Allocating funds for seed kits, monitoring tools, and extension services ensures that trials are scientifically robust and practically viable.
- **Seed Fairs and Exchange Platforms:** Facilitating knowledge-sharing events and seed exchanges fosters community learning, promotes genetic diversity, and strengthens social cohesion.
- **Honorariums and Incentives:** Recognizing and compensating farmers for their time and expertise promotes equity and affirms the value of their contribution.

Furthermore, clear metrics should be developed to evaluate the effectiveness of farmer participation, including adoption rates, cost savings, and yield improvements. Such evidence-based approaches can help guide policy formulation, donor engagement, and program replication.



Conclusion – A Call for Participatory and Accountable Development

The future of resilient agriculture lies in the effective and equitable partnership between scientific innovation and grassroots knowledge. By embedding participatory plant breeding into the core of agricultural strategy, we can co-create seed solutions that are not only climate-resilient and high-yielding but also socially inclusive and economically sustainable.

Farmers should be recognized as co-creators, not just consumers, of agricultural technology. Their experiential insights, when harmonized with modern science, produce superior outcomes that benefit entire ecosystems economic, social, and environmental.

We therefore call upon all stakeholders NGOs, research institutions, policy makers, and funding agencies to adopt a participatory development model rooted in mutual respect, accountability, and knowledge co-creation. This means planning and budgeting for farmer involvement not as an expense, but as an investment one that pays dividends in resilience, productivity, and dignity.

In an era where agricultural systems are under unprecedented strain, we must build a future where local voices guide innovation, and where every seed sown is a testament to collective effort and shared hope.



Cultivating Resilience

Traditional Seeds and the Future of Farming

Author: Anolita Singho, Communication Officer, PFRI

Introduction

I was raised in cities, like most of us are far away from farms. I never tilled the soil or planted a seed. The only real interaction I had with the land was during visits to my grandparents' farmhouse in the village. My grandpa used to grow all sorts of vegetables and fruits, and somehow, they always felt far superior in quality compared to what we were used to buying in the city.

It wasn't until years later, while reporting in Chandigarh, that I started to revisit those early impressions. This time, through the eyes of the people who live that life every day. Back then, I heard a lot of stories about how, year after year, the earth seemed more brutal for growing crops. Stories of entire harvests wiped out by unexpected rains, heatwaves, and long droughts. But even among those stories, there were farmers whose crops went seemingly unharmed through these climate anomalies.

I was intrigued. In my conversation with them, I found out they were still using older, local methods of farming and seeds that had been passed down through generations in their communities. I realized I was seeing resilient agriculture and agrobiodiversity in action. Two words I hadn't even heard of until recently.

The more I invested myself in this space, the more I understood: the seeds we sow today not only determine what we grow, but what survives and gets passed down to the generations of tomorrow. For thousands of farmers across India, who are facing increasingly erratic climate conditions. Resilience begins with remembering. With holding on to traditional seeds and farming practices handed down through generations.

This piece is a reflection of what I've observed, read, and learned from those living closest to the soil.

Seeds as Memory, Seeds as Resistance

One of the things I never truly understood until I started listening to farmers closely, was how deeply personal a seed could be. To someone like me, a seed was just a starting point. To them, it was memory. An inheritance. A way of saying, "This worked for my ancestors, and it will work for me". They've survived because generations of farmers observed, selected, saved, and shared what worked best for their specific land and climate.

I think what struck me most was how all of this exists below the radar. You don't hear about these farmers on the news or see them celebrated on social media. But they are the ones who are quietly keeping agrobiodiversity alive not because it's trendy, but because it's what works. Their seeds don't need chemicals because the land still remembers how to sustain itself.

And the more I learned, the more I realized this isn't just about the past. This is about survival. In a world where climate patterns are unpredictable, and soil is losing fertility fast due to chemical overuse, these traditional methods built on diversity and seed saving might be what helps us adapt. They hold memory, resilience, and possibility all at once. And they remind us that maybe the future of farming isn't about inventing something new, it's about not forgetting what already works.

Farming Through Climate Chaos Soil, Survival, and Smarter Practices

A common thread I noticed in every farmer conversation no matter the state or the crop was how unpredictable the weather had become. They weren't talking in terms of climate change or carbon emissions. They were talking about how the rains no longer came when expected, how the summers felt harsher, how the soil wasn't what it used to be.

I met a farmer who told me he'd gone back to basics, cow dung, compost, cover cropping, crop rotation. Not because he couldn't afford chemical fertilizers, but because he didn't trust it anymore. This was my introduction to what people now call regenerative farming - letting the soil rest, planting legumes to fix nitrogen, mixing crops so no single pest could wipe them out.

One of the contradictions I kept hearing about was that the newer, industrially developed seeds could deliver amazing yields but they require perfect irrigation, regular chemical fertilizers, controlled environments. The moment there was a delay in rainfall, or an unexpected heatwave. These crops would collapse. Meanwhile, some of the older seed varieties, the ones passed down through generations, might not give double yields, but they knew how to survive. They'd been bred over time to handle stress, not lab stress, but real-world chaos. When combined with organic methods that kept the soil healthy and breathing, these traditional seeds showed remarkable strength.

There's a reason farmers call the soil their "mother." The more I listened, the more I understood the connection between healthy soil and resilient farming. The farmers who had invested in their soil were the ones weathering the chaos better. These weren't isolated cases. Across the country, small pockets of organic and regenerative farmers are proving that working with nature still works.

The Way Forward – Remembering is Resilience

The biggest thing I've taken away from all of this is that resilience doesn't always look revolutionary. Sometimes, it looks like someone simply continuing what their grandparents taught them. In the middle of a climate crisis, where everything feels like it needs a big new solution, maybe what we really need is to listen backwards.

Of course, they aren't without challenges. It's not easy to go organic when chemical agriculture still dominates government subsidies and marketplaces. And it takes courage to stick to traditional seeds when hybrids promise higher returns. But the farmers who are doing it are proving that sustainable farming isn't a nostalgic idea. It's practical and with each passing season, it's becoming more urgent.

For me, as someone who came into this world as an outsider, all of this has been a reminder of how much we still don't value what's already working. It's easy to overlook the quiet success stories, the farmers protecting their soil, saving their seeds, looking after their land. And yet, these are the people quietly doing the work that matters most. What they're holding onto isn't a trend, it's the foundation.

The path forward isn't just about technology or innovation. It's about remembering the knowledge of the soil and the strength in simplicity. In the end, survival might not depend on what we invent, but on what we choose not to forget.

Between Beauty and Biodiversity

*Author: Archisman Guha, Independent Researcher,
Kolkata*



Lead Paragraph

Darjeeling, the ‘Queen of the Hills,’ is celebrated for its breathtaking landscapes, tea gardens, and cultural richness. Yet beneath the allure lies a fragile ecosystem increasingly burdened by unregulated tourism and rapid urbanization. This piece explores how Darjeeling’s natural splendor and biodiversity face mounting pressures, and how communities, policies, and sustainable tourism models might offer a way forward

Context

Perched within the Eastern Himalayas, Darjeeling is both a cultural icon and an ecological treasure. Known as the ‘Queen of the Hills,’ it forms part of a global biodiversity hotspot with landscapes ranging from lush subtropical forests to alpine meadows above 3,600 meters. This altitudinal diversity nurtures rare and endangered species such as the red panda, clouded leopard, and Himalayan monal, alongside more than a hundred species of orchids and medicinal plants long valued by local communities. Darjeeling’s history is equally layered. A frontier district of West Bengal, it has evolved into a melting pot of communities, Nepali-speaking Gorkhas, Lepchas, Bhutias, Tamangs, and others each shaping the region’s cultural vibrancy. Four hill towns, Darjeeling, Kalimpong, Kurseong, and Mirik anchor the region’s economy and identity, with Darjeeling town at its heart.

Tourism here has deep roots. What began in the colonial era as a retreat for British officials has grown into one of the region’s largest industries, second only to tea. Today, millions visit annually, drawn by mountain vistas, the heritage railway, and the promise of cool, clean air. Yet, as visitor numbers swell, so too do the challenges. Forests give way to hotels, roads cut across fragile slopes, and seasonal peaks strain waste management and water supply. The very landscapes that make Darjeeling a global attraction now stand at risk of erosion, both ecological and cultural.

Environmental Impact

Darjeeling’s hills are alive with biodiversity. Rhododendrons paint slopes crimson each spring, magnolias bloom in pale pink, and bamboo groves rustle alongside ancient oaks. The forests shelter elusive species such as the red panda, Himalayan black bear, and clouded leopard, while birdwatchers flock to spot the iridescent Himalayan monal or the rare satyr tragopan. Butterflies like the Kaiser-i-Hind glide through the forests, adding flashes of color to the misty trails. But the same forests are under pressure. Tourism, once seen as a ‘clean industry,’ now casts a long ecological shadow. Expanding hotels and resorts often mean felling trees and fragmenting habitats. Roads built to connect tourist hotspots cut across wildlife corridors, disturbing animals in their breeding and feeding grounds.

Waste generation especially plastics and sewage are rising sharply, with fragile ecosystems like Singalila National Park and Senchal Wildlife Sanctuary absorbing the burden. Seasonal peaks amplify these stresses, when tens of thousands of visitors converge during summer and winter holidays, overwhelming the region’s carrying capacity.

Tourism does bring awareness and revenue, sometimes funding conservation and providing livelihoods for local families. Community-based homestays and eco-tourism ventures in villages near trekking routes show how visitors and biodiversity can co-exist. Yet the balance remains precarious. Without stronger safeguards, the growth of mass tourism risks eroding the very natural beauty that draws people to Darjeeling in the first place.

Community Voices

Behind the postcards of snow peaks and tea gardens are the people who call Darjeeling home. The hills are a mosaic of communities Nepali-speaking Gorkhas, Lepchas, Bhutias, Tamangs, and others who have built their lives around the land and its resources. For many, the tea industry remains the backbone of daily survival. Over 80 estates across the district employ tens of thousands, yet wages are often low and living conditions on the estates remain modest. Tourism offers another lifeline. Families run small homestays, drive shared jeeps, or

guide trekkers along the Singalila trail. For some, the tourist season brings a welcome boost in income. But it is also unpredictable. A heavy monsoon, a political strike, or a pandemic can wipe out earnings for months, leaving households vulnerable. Many young people migrate to cities or abroad for work, sending back remittances that sustain their families in the hills.

The strains of unplanned tourism also touch daily life. Housing pressures rise as land is diverted for hotels and resorts. Waste disposal becomes a community problem, with streams and roadsides turning into dumping grounds during peak season. Residents often shoulder the cost of rising prices in food, water, and transport as demand surges with the tourist influx. And yet, there is resilience. Local groups and youth collectives have pioneered waste-free treks, biodiversity monitoring, and eco-tourism ventures in villages like Tumling and Tonglu. For these communities, conserving forests and wildlife is not only about protecting nature it is about protecting their own future. Their voices call for a balance between livelihoods and landscapes, so that Darjeeling’s people and biodiversity can thrive together.

Lessons Learned

Objectives

The central aim of this work was to explore how tourism shapes biodiversity in Darjeeling. Specifically, it sought to examine patterns of habitat loss and fragmentation, evaluate human pressures such as waste and land-use change, and review how conservation frameworks and community models respond to these challenges.

Methodology

Rather than relying on a single dataset, the study drew on a wide spectrum of sources: ecological field surveys, remote sensing analyses, government and NGO reports, and community-level studies. Special attention was paid to comparing disturbed areas (such as tea gardens or roadside forests) with relatively undisturbed sites like Singalila National Park. This mixed approach provided a fuller picture of how tourism interacts with ecosystems across seasons and landscapes.

Literature Review

Insights from across the Himalayas and beyond reinforce the urgency of Darjeeling's case. Tourism is now one of the most significant pressures in biodiversity-rich areas worldwide, with impacts ranging from habitat conversion to waste pollution. In mountain systems, even modest increases in visitor numbers can destabilize fragile ecological processes.

Indian studies highlight similar patterns in Sikkim, Himachal Pradesh, and Uttarakhand, where unregulated tourism strains local environments. Darjeeling mirrors these trends, with forests receding, species stressed, and waste rising sharply in protected areas.

Results

The findings reveal a strong correlation between tourist growth and environmental degradation in Darjeeling. Annual visitors increased nearly tenfold between 1990 and 2023, while forest cover declined by more than 10% in the same period. Waste generation soared from an estimated 50 tons per year in 1990 to nearly 1,000 tons annually today. Wildlife disturbance indices also rose, with species such as the red panda and Himalayan black bear increasingly displaced from their natural ranges. At the same time, small but promising conservation initiatives including community-based ecotourism, seasonal restrictions in sensitive zones, and biodiversity education campaigns demonstrate that alternatives are possible when communities and authorities work together.

Policy Reflections

Strategies for Sustainable Tourism

Tourism in Darjeeling needs a decisive shift from quantity to quality. Carrying capacity assessments can help set limits on visitor numbers in fragile zones such as Singalila and Tiger Hill. Zoning laws must prevent unplanned hotels, resorts, and parking lots from encroaching into forests and wildlife corridors. By introducing eco-certification for operators and mandating environmental impact assessments for all new projects, tourism can move closer to being part of the solution rather than the problem.

Community Participation

Local communities hold the key to balancing livelihoods and landscapes. Expanding homestays, community-run trekking routes, and benefit-sharing schemes ensures that tourism revenue circulates within the hills. Training youth as eco-guides and involving them in biodiversity monitoring empowers residents to act as custodians of their environment.

Green Infrastructure and Waste Management

Without better waste systems, tourism's footprint will continue to grow. Investment in solid waste treatment, plastic-free campaigns, and eco-friendly transport such as electric shuttles or cable cars is essential. Decentralized waste segregation and composting in villages near trekking routes can reduce the load on municipal systems.

Restoration and Research

Tourism policy must go hand in hand with ecological restoration. Reforesting degraded slopes with native species, protecting wildlife corridors, and rehabilitating abandoned construction sites can revive ecosystems. At the same time, long-term biodiversity monitoring through GIS mapping, drones, and citizen science will provide the data needed to adapt strategies over time. Partnerships with research institutes and NGOs can anchor these efforts in science and local knowledge.

Closing Insight

Darjeeling's future lies in finding harmony between its beauty and its biodiversity. Tourism has long been the region's strength, but unmanaged growth now risks undermining the very landscapes that make it thrive. The lesson is clear: prosperity and preservation cannot be pursued in isolation. By embracing community-led models, enforcing ecological safeguards, and investing in green infrastructure, Darjeeling can show that mountain tourism need not come at the cost of its forests, wildlife, and cultural heritage.

In doing so, the 'Queen of the Hills' could stand as more than a destination—it could become a living example of how people and nature flourish together, offering a roadmap for other fragile regions across the Himalayas and beyond.

NEWS HAMLET





Challenges and Opportunities for Climate Resilient Agriculture in Eastern India

*A Case Study of Udaynarayanpur,
West Bengal*

Author: Somnath Samantha, Research Assistant, PFRI



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Introduction

India is a predominantly agricultural country. Among all regions, Eastern India has further enhanced our identity as an agriculture-based nation (Singh *et al.*, 2019). Agriculture is at the core of our economy (Rao *et al.*, 2020). Eastern India, encompassing regions like West Bengal, Bihar, Jharkhand, and parts of Assam, mostly relies on farming. In recent years, climate change has attracted growing concern as an obstacle to development. Nations across the globe are facing the impacts of climate change through rising mean temperatures, fluctuations in rainfall patterns, and more frequent extreme weather events (Goswami *et al.*, 2023). However, the region is highly vulnerable to climate change impacts such as erratic rainfall, floods, droughts, cyclones, and soil degradation. Climate-resilient agriculture (CRA) is an approach that promotes the sustainable use of existing natural resources through integrated crop and livestock production systems, aiming to enhance long-term productivity and farm incomes in the face of climate variability (Sahoo *et al.*, 2025).

Case Study

The area of study part of the Udaynarayanpur block. Udaynarayanpur is a community development block located in the Howrah district of West Bengal, India. It forms part of the Howrah Sadar subdivision and is primarily rural in character. Our study area located from 22°43'01" N, 22°36'54" N to 87°58'30" E, 87°58'06" E. The block covers an area of approximately 113.45 square kilometers and comprises several gram panchayats, including notable villages such as Bhawanipur, Garh Bhabanipur, Chitrasenpur, Bidhichandrapur, and Raghunathpur.

Geographically, Udaynarayanpur is situated on the western side of the Hooghly and Damodar River is generally non-perennial river by nature, and is characterized by fertile alluvial soil, which makes agriculture the predominant occupation of the residents. Udaynarayanpur, West Bengal experiences a tropical Indian climate with distinct seasonal temperature variations. The hottest months are March and June, with average temperatures reaching 35°C and 27°C, respectively. The cooler months, typically from October to February, see average temperatures ranging from 31°C to 21°C. The monsoon season, from June to September, brings high humidity and rainfall, with temperatures averaging around 32°C to 26°C.

The area constitutes with the highest rainfall in the month of June, July and August having the average rainfall of 150-160 cm. Depending on the climate, paddy, wheat, pulses, jute, vegetables, and other seasonal crops are cultivated in this region.

According to the latest census data, the block has a diverse population with a balanced male-to-female ratio and a relatively high literacy rate compared to other rural regions of West Bengal. The area is served by a network of local roads, educational institutions, healthcare centres, and basic public services, although further development is ongoing.

Culturally, Udaynarayanpur reflects the traditional Bengali rural lifestyle, with festivals, folk traditions, and community participation playing an important role in the social fabric of the villages.

Climate Resilient Agriculture

1. Diversification of Crops and Cropping Patterns: Crop diversion strategies entail altering the types of crops cultivated in response to changing climatic conditions, soil health, and market demand (Sarma *et al.*, 2024).

Since this region is situated on the banks of the Damodar River, there is no shortage of water, which allows for the cultivation of various types of crops. Promote climate resilient crop varieties (e.g., drought-tolerant rice, short duration pulses, oilseed). Encourage crop diversification, such as paddy, pulse, oilseed, ground nut and horticulture. Intercropping and mixed farming to reduce climate risk.

2. Soil health improvement: Damodar is called the "Sorrow of West Bengal" because almost every year during the monsoon season, this river overflows its banks and causes floods in the Udaynarayanpur area. As a result, a large amount of fertile alluvial soil gets deposited in the flood-affected regions. Along with the alluvium, a significant quantity of parasitic weed seeds also floats in and settle in these areas. Consequently, after the flood, various new types of weeds grow in large numbers, which degrade the natural quality of the soil. Improving soil health can strengthen the resilience of agricultural systems under changing climatic conditions. Various measures have been undertaken to boost soil organic carbon, increase moisture retention capacity, and minimise soil degradation, all of which can potentially bolster soil resilience (Rao *et al.*, 2020). To restore the soil's natural fertility, organic fertilizers are used, and climate-resilient crops (such as Indian Pea and Black-eyed Pea) are cultivated.

3. Agroforestry and Integrated Farming Systems:

Combining crops, livestock, agroforestry and afforestation (Goswami *et al.*, 2023). In this region, along with farming, a significant amount of agroforestry is practiced along the boundaries of the land. Incorporate trees in farmland to buffer against climate extremes. The reason for this is to increase crop production and to protect the crops from insects and animals. Enhances income resilience and efficient use of natural resources. Through agroforestry, plants like tulsi (holy basil), tuberose, and marigold are cultivated to repel insect infestations. Additionally, plants such as Ipomoea carnea, Lantana camara, Justicia adhatoda, and Vetiver are used as natural fencing to protect crops from cattle and goat intrusion. Increasing tree cover to improve soil moisture and reduce erosion.

4. Water Management Techniques:

Promoting rainwater harvesting, micro-irrigation (drip and sprinkler), and farm ponds. Water harvesting will be advantageous for any resource-conserving adaptation initiative in water governance, as heightened rainfall results in surface runoff, while rising temperatures may elevate the demand for evapotranspiration (Karri & Nalluri, 2023). Since this area is flood-prone, aquaculture is a secondary livelihood here alongside agriculture. As a result, a large number of aquaculture ponds have been created. Encouraging alternate wetting (Sona Masoori) and drying (Bashanti/Basmati) in paddy fields to reduce water use and methane emissions. Use of climate information services for irrigation scheduling.

5. Weather and Climate Advisory Services:

Disseminating real-time weather forecasts and crop advisories through mobile apps, radio, and propagation through people (*local networks*). Training farmers in risk management and adaptive planning.

6. Technological Advancements: Agriculture's susceptibility to climate change is largely attributable to its significant dependence on temperature, rainfall, and climatic conditions. At present, due to global warming, weather patterns around us are changing, and our region is no exception (Vetri Selvi *et al.*, 2025). As a result of climate change, the usual characteristics of weather at specific times are no longer observed. This change in climate is having an adverse effect on agriculture. To protect crops from these effects, new methods are being adopted, one of the most notable being the use of climate-resilient agricultural seeds. These seeds have an exceptional ability to adapt to environmental changes and have a higher yield capacity compared to regular local seeds.

For example: Drought tolerance seeds - Varuna (Mustard), TMV 2 (Groundnut), Pusa Vishal (Pigeon Pea), Sahbhagi Dhan (Paddy) and Flood tolerance seeds: Swarna-Sub1, Sambha Mahsuri - Sub1 (Paddy), Rajdeep (CR Dhan 401), Nirmal -7 (Khersari), Maitree (Lentil), JRO 524 (Jute).

7. Capacity Building and Institutional Support:

Strengthening farmers' cooperatives and self-help groups (SHGs) to implement climate-smart practices. Government programs like National Mission for Sustainable Agriculture (NMSA) and PM- Kisan Samman Nidhi play a vital role.

8. Climate Insurance and Financial Inclusion:

Due to the current adverse changes in weather, there is at times excessive rainfall leading to floods, and at other times a lack of rain causing droughts. As a result, these adverse weather changes have a negative impact on crop production. This creates financial uncertainty for people involved in agriculture. To protect the farming community from this uncertainty, certain climate insurance and financial inclusion initiatives have been introduced. Crop insurance schemes like PMFBY need better implementation and awareness. Access to credit for climate-resilient inputs and technologies.

Challenges of Climate Resilient Agriculture

I. Climatic Challenges: The occurrence and persistence of rainfall have increased due to global climate change, which negatively influences plant growth and development. These unpredictable rainfall patterns often result in hardships, either in the form of drought or flooding, which could lead to serious damage in the near future (Bhattacharyya *et al.*, n.d.).

a. Frequent inundations: Every year, Eastern India faces floods. During the monsoon season, excessive rainfall in Jharkhand and West Bengal, combined with the Damodar Valley Corporation (DVC) releasing water due to its inability to control it, leads to annual flooding in this region along the banks of the Damodar River. As a result, there is significant agricultural loss and financial damage, which are major consequences of climatic changes in this area.

b. Erratic rainfall: Unpredictable monsoons disrupt sowing and harvesting cycles. In our region, due to insufficient rainfall during the summer season, a shortage of water is observed. On the other hand, during that time, DVC is also unable to supply adequate water to the canals and wetlands that rely on small amounts of rainwater. As a result, there is a noticeable scarcity of water for agriculture, which is considered one of the major challenges.

c. Cyclones: Due to the increasing frequency of cyclones like Amphan and Yaas, crops such as rice, maize, and sugarcane suffer extensive damage, resulting in lower-than-expected agricultural production. This leads to significant agricultural losses.



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II. Environmental and Agronomic Issues

a. Declining soil fertility: Due to the excessive use of chemical fertilizers and pesticides in the hope of increasing crop production, the natural qualities of the soil are gradually deteriorating.

b. Agrobiodiversity loss: Climate-resilient indigenous crops are being replaced with high-yielding but fragile varieties.

III. Socio-Economic Constraints

a. Small and marginal landholdings: At present, due to family disputes, the land is being divided into smaller plots. As a result, the expected level of crop production is not being achieved, which is seen as a challenge.

b. Poverty and indebtedness: Farmers often lack the financial resources to adopt new practices.

c. Gaps in literacy and socio-cognitive awareness: Obstructs comprehension of climate change effects and adaptation approaches.

d. Migration: Migration of younger generations to urban centres reduces manpower for farming and threatens the inheritance of agricultural knowledge.



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IV. Infrastructural and Technological Gaps

a. Substandard irrigation equipment: Eastern India has limited irrigation coverage compared to other regions. In our study area, there is no well-structured irrigation infrastructure. As a result, it is not possible to irrigate crops during the summer, leading to insufficient agricultural production, which is one of the major challenges.

b. Inadequate storage and limited market access: Leads to post-harvest losses and low profitability.

c. Traditional farming techniques: Most farmers still practice agriculture using old methods and outdated equipment from ancient times.

d. Limited access to weather forecasts: Timely meteorological information is often unavailable to farmers, hindering well-informed decisions.

V. Policy and Institutional Barriers

- Inadequate presence of trained farming outreach workers.
- Climate-resilient initiatives often suffer from poor coordination and monitoring.
- Crop insurance schemes have not reached a majority of smallholders.
- Obstacles in acquiring financial support from institutions for climate-friendly initiatives.

Suggestions for Improvement

- Encouraging adaptive agricultural methods (e.g., agroforestry, local crop diversification).
- The implementation of climate-resilient agricultural (CRA) practices is inconsistently recorded in academic literature. Further empirical research is needed to determine which practices are adopted specifically in contextually relevant settings.
- The key insight regarding on-farm adaptation measures, which are largely traditional, is that they require further validation before being scaled up to other regions. Modernization of rural farming infrastructure (e.g., cold storage, irrigation).
- Strengthening local institutions and farmer cooperatives.



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CONCLUSION

Climate change and variability are affecting agricultural production globally; however, a developing nation like India is more severely impacted due to a higher reliance on farming, depletion of natural resources, and inadequate recovery mechanisms (Goswami et al., 2023). Eastern India, while grappling with significant agro-climatic and infrastructural challenges, sustains its productivity through the large-scale cultivation of climate-adaptive crops such as potato, paddy, jute, sugarcane, and multiple pulse species.

By combining traditional knowledge with scientific advancements, and ensuring strong institutional support, Eastern India can become a model for climate-resilient agriculture in the global south. So just think for a moment how far we can progress by utilizing advanced infrastructure. And one more thing, no matter how advanced the world becomes, if agriculture does not exist, food scarcity will arise in every corner of the world. Therefore, before building a developed village, state, nation, or world, we must first properly organize and sustain the agricultural sector for future generations. By doing so, we can gift a beautiful, toxin-free world to the generations to come.

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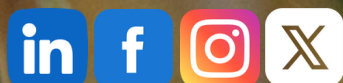
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