Wetlands and Makhana Cultivation: A Geographical Study in North Bihar

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https://doi.org/ 10.61410/had.v21i1.270

Abstract

North Bihar's wetlands, including chaurs, mauns and ponds; are vital for makhana (Euryale ferox) cultivation, producing 90% of global output (15,000 ha, 10,000 tonnes popped makhana). Makhana is a high-value aquatic crop and GI-tagged superfood that sustains the livelihoods of over four lakh farmers of Bihar and has emerged as climate-resilient farming options in flood-prone and waterlogged regions of Bihar. Its unique adaptability to stagnant and shallow aquatic ecosystems makes it an ideal crop for areas frequently affected by excessive rainfall, prolonged submergence and soil saturation-conditions that hinder conventional agricultural production system. The climatic resilience attributes of makhana cultivation, including its tolerance to waterlogging, efficient nutrient recycling and compatibility with integrated farming systems such as fish-makhana-vegetable models. This review examines makhana cultivation through a geographical lens, focusing on spatial distribution, environmental influences and socio-economic dynamics in districts like Darbhanga, Madhubani and Purnea. Breeding innovations, such as the Sabour Makhana-1 and Swarna Vaidehi varieties and shallow-water farming enhance resilience to floods, while challenges like pollution, encroachment and limited mechanization persist. Socio-spatial analyses highlight the Mallah community's role, land leasing practices and seed access disparities. Policy initiatives, including the Makhana Board and Geographical Indication (GI) tag for Mithila Makhana, aim to boost exports and farmer incomes. Drawing on literature from 2012 to 2025, this study underscores the role of geographical approaches in enhancing Makhana's contribution to food security and sustainable agriculture in North Bihar's flood-prone landscapes.

Keywords: Climate resilience, GIS, Makhana, Spatial analysis, Wetlands, North Bihar

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Introduction

Wetlands in North Bihar are widely distributed across the floodplains of major Himalayan Rivers such as the Kosi, Gandak, Bagmati, Kamla and Mahananda, forming a dense network of water bodies due to the region's low-lying topography and recurrent flooding. These wetlands are highly dynamic and are primarily classified into natural and man-made types. Natural wetlands include oxbow lakes (locally called chaur), marshes, swamps, floodplain lakes and riverine wetlands formed by meandering rivers, while man-made wetlands consist of ponds, tanks and waterlogged agricultural fields modified for activities like fisheries and makhana cultivation. The northern districts such as Darbhanga, Madhubani, Sitamarhi, Supaul, Saharsa, Purnea and Katihar have particularly high wetland density, with seasonal and perennial wetlands coexisting depending on monsoon patterns and river behavior. These wetlands are typically shallow, nutrient-rich, and alluvial in nature, making them ecologically productive and suitable for aquatic crops. Their distribution is largely influenced by annual flooding, sediment deposition, and drainage patterns, resulting in a mosaic of interconnected aquatic ecosystems that play a vital role in biodiversity conservation, groundwater recharge, and sustaining rural livelihoods in North Bihar**.**

Makhana (*Euryale ferox*) is a high-value aquatic crop and GI-tagged superfood that sustains the livelihoods of over four lakh farmers of Bihar. Makhana seeds are highly nutritious, rich in protein, carbohydrates, fiber and essential minerals; packed with potent antioxidants (Lee et al., 2002; Jiang et al., 2023) and flavonoids, they boast low fat, low sodium, and low cholesterol profiles along with a low glycemic index (Kapoor et al., 2022). India leads global Makhana production, with Bihar contributing about 80-85% of the world's supply. In India, from 2020 to 2025, area under cultivation increased by 40–50% (25,000–27,000 to 35,000–40,000 hectares), and production nearly doubled (32,000–35,000 to 60,000–63,000 MT). The crop holds GI tag (Mithila Makhana) and is gaining export demand in markets like the US, Canada and Australia. Indian Makhana exports increased nearly four times from 6,700 MT (2020) to 25,130 MT (2024) and India holds immense potential to establish makhana as a premium superfood snack in high-growth global markets, commanding 8-11% CAGR in health-conscious regions like the United States, European Union, Middle East and Southeast Asia (ICRIER and APEDA, 2025).

Makhana supports livelihoods, particularly for the Mallah fishing community. North Bihar's wetlands - chaurs (seasonal floodplains), mauns (oxbow lakes) and ponds - span 403,209 ha (4.4% of Bihar's area), offering ideal conditions due to waterlogged alluvial soils and monsoon-driven hydrology (Bihar Wetlands Atlas, 2023). Low productivity, environmental degradation (pollution, encroachment) and socio-economic barriers (limited mechanization, seed access) constrain Makhana cultivation (Kumar et al., 2020). Climate variability, with 1,205.6 mm annual rainfall and frequent floods, complicates production, necessitating resilient practices (Jana et al., 2018). Innovations like the Swarna Vaidehi and Sabour Makhana-1 varieties and shallow-water farming have improved yields, while policies like the Makhana Board and GI tag for Mithila Makhana enhance market access (Makhana Vikas Yojana, 2023).

This review adopts a geographical perspective, analyzing makhana cultivation in North Bihar through spatial distribution, environmental influences, and socio-economic dynamics. It examines breeding and management strategies for climate resilience, socio-spatial farmer patterns, and policy impacts. This study aims to guide geographers, policymakers and researchers, highlighting makhana's role in sustainable wetland management and food security in North Bihar's flood-prone landscapes.

Wetlands as Agro-Ecosystems and Its Ecological Significance

Wetlands are among the most productive ecosystems on Earth and play a crucial role in maintaining ecological balance and supporting livelihoods. According to the Ramsar Convention, wetlands are defined as areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with static or flowing water, including fresh, brackish, or saltwater bodies up to six meters in depth at low tide. Based on origin and characteristics, wetlands are broadly classified into natural and man-made types. Natural wetlands include riverine floodplains, oxbow lakes, marshes, swamps and inland depressions formed through natural hydrological processes, while man-made wetlands consist of ponds, tanks, reservoirs, irrigation canals and waterlogged agricultural lands developed for human use such as irrigation, fisheries and makhana cultivation. In India, wetlands are distributed across diverse regions, including Himalayan lakes, coastal lagoons, floodplains and arid zone depressions, with the Indo-Gangetic plains representing one of the most significant wetland systems. Within this region, Bihar holds a prominent position due to its flat terrain and dense river network. The North Bihar region, in particular, is characterized by extensive floodplain wetlands formed by rivers such as Kosi, Gandak, Bagmati and

Kamla, which frequently change their course and deposit sediments, creating a mosaic of oxbow lakes (chaur), marshes, and seasonal waterlogged areas. These wetlands are shallow, nutrient-rich and highly dynamic, making them ideal for aquatic agriculture, especially makhana cultivation. Thus, the wetland distribution in North Bihar not only reflects its unique geomorphology and hydrology but also underpins the region's agro-based economy and livelihood systems.

Wetlands function as highly productive agro-ecosystems that play a significant role in supporting agriculture, particularly in floodplain regions such as North Bihar. Their nutrient-rich soils, natural water availability and favorable microclimatic conditions make them suitable for cultivating a variety of crops, especially aquatic and semi-aquatic species like makhana (Euryale ferox) and paddy. Wetlands contribute to agricultural sustainability by maintaining soil fertility through continuous nutrient deposition and by providing a reliable water source, reducing dependence on irrigation infrastructure. In many areas, farmers adopt integrated farming systems within wetlands, combining crop cultivation with fisheries, livestock rearing and aquatic horticulture, which enhances resource-use efficiency and diversifies income sources. For example, makhana-cum-fish culture is a common practice in North Bihar, where both activities coexist and mutually benefit from the same ecosystem. Moreover, a large section of the rural population is directly dependent on wetlands for their livelihoods, including farming, fishing, harvesting of aquatic products and related processing activities. These systems generate employment opportunities, particularly for marginal and small farmers, and contribute significantly to food security and income generation. Thus, wetlands as agro-ecosystems are crucial for sustaining rural economies while promoting environmentally compatible agricultural practices.

Makhana Cultivation Practices in Wetlands

Makhana cultivation spans 15,000 ha in North Bihar, concentrated in Darbhanga, Madhubani, Sitamarhi, Purnea, Araria, Katihar, Kishanganj, Madhepura, Saharsa and Supaul accounting for 80% of Bihar's output (Saurav & Chandran, 2023). GIS-based mapping reveals cultivation patterns tied to wetland types: chaurs (40% of area), mauns (30%) and ponds (30%) (Kumar et al., 2020). Darbhanga and Madhubani, with chaurs like Kusheswarasthan, lead production (1.2–1.5 t/ha seeds), while Purnea's pond systems support higher-density planting (Mishra et al., 2023). Spatial analysis identifies environmental drivers. North Bihar's flat topography (30–60 m elevation) and alluvial soils (pH 6.5–7.5) suit makhana, with water depths of

0.5–1.5 m optimal (Bihar Wetlands Atlas, 2023). Monsoon rainfall (1,205.6 mm, June–September) ensures water availability, but variability disrupts sowing (April–May) and harvesting (August–September) (Jana et al., 2018). Remote sensing (Sentinel-2, Landsat-8) shows seasonal wetland expansion, with chaurs covering 200,000 ha during peak floods (Nair & Singh, 2024).

Figure-1: Makhana growing districts of Bihar

managed chaurs support Mallah farmers, while Purnea's private ponds, leased to entrepreneurs, yield higher profits but exclude smallholders (Singh & Kumar, 2018). GIS suitability models suggest 50,000 ha of untapped wetlands in Supaul and Araria, but encroachment and pollution reduce viable areas by 20% annually (Kumar et al., 2020). Spatial clustering (Moran's I = 0.65) indicates high cultivation concentration in flood-prone districts, highlighting the need for resilient practices (Nair & Singh, 2024).

Table-1: Wetland Types Supporting Makhana Cultivation in North Bihar

Wetland Type	Area (ha)	Cultivation Area (ha)	Yield (t/ha seeds)	Key Districts	Management
Chaur	200,000	6,000	1.2-1.5	Darbhanga, Madhubani	Community-based
Maun	100,000	4,500	1.0-1.3	Saharsa, Supaul	Mixed (private/community)
Pond	103,209	4,500	1.3-1.6	Purnea, Katihar	Private leasing

Source: Bihar Wetlands Atlas, 2023; Kumar et al., 2020; Mishra et al., 2023.

Wetland–makhana interaction

The interaction between wetlands and makhana cultivation represents a unique agro-ecological relationship in which natural ecosystem characteristics directly influence crop productivity and sustainability. Wetlands provide ideal conditions for makhana growth, including stagnant or slow-moving freshwater, appropriate water depth and nutrient-rich alluvial sediments that support vigorous plant development. Water depth plays a critical role, as shallow to moderately deep water ensures proper leaf expansion, flowering and seed formation, while excessive depth or drying can adversely affect yield. Similarly, sediment quality influences nutrient availability, with silt deposition enhancing soil fertility but excessive sedimentation reducing effective water depth and hindering cultivation. The ecological environment of wetlands, including biodiversity and microbial activity, further contributes to maintaining soil health and natural nutrient cycling, which reduces the need for external inputs. However, changes in wetland ecology due to climate variability, pollution or human interference can negatively impact makhana productivity. Despite these challenges, makhana-based wetland farming is considered relatively sustainable, as it utilizes natural resources efficiently, supports biodiversity and provides livelihood security without intensive chemical inputs. Ensuring the conservation and scientific management of wetlands is therefore essential for sustaining this integrated agro-ecosystem in the long term.

Environmental Influences on Makhana Productivity

Climate and Hydrology- North Bihar’s monsoon climate (1,205.6 mm rainfall, 25–35°C) supports makhana, with water availability critical for germination and fruiting (Jana et al., 2018). Floods from rivers like Kosi and Gandak replenish wetlands but can delay sowing or damage crops, reducing yields by 20–30% in high-flood years (Pandey & Gupta, 2024). Erratic rainfall (10% increase since 2010) challenges traditional calendars, necessitating flood-tolerant varieties (Chaudhary et al., 2022).

Soil and Water Quality-Alluvial soils with organic matter (1.5–2%) and nitrogen support makhana's nutrient needs, while water pH (6.5–7.5) and low salinity (<1 dS/m) are ideal (Kumar et al., 2020). Pollution from agricultural runoff (nitrates, pesticides) and urban waste degrades 30% of wetlands, impacting seed quality (Mishra et al., 2023). Remote sensing indices (e.g., NDWI) monitor water quality, guiding site selection (Nair & Singh, 2024).

Wetland Ecology- Wetlands host diverse flora (e.g., water hyacinth) and fauna (e.g., fish), enabling integrated makhana-pisciculture systems that boost incomes by 15% (Singh & Kumar, 2018). Invasive species and siltation reduce water depth, affecting makhana's habitat (Kumar et al., 2020). Dredging mauns has restored 10,000 ha since 2015 (Bihar Wetlands Atlas, 2023).

Climate Change Impacts- Makhana faces multiple constraints that limit its productivity and profitability. One of the major challenges is its high dependence on specific water and climatic conditions, as fluctuations in water depth, erratic rainfall, floods or droughts can significantly affect crop growth and yield. Rising temperatures (0.5°C/decade) and flood frequency shorten makhana's fruiting period by 5–7 days, reducing seed size (Pandey & Gupta, 2024). Breeding for heat-tolerant varieties like Swarna Vaidehi mitigates impacts (Kumar et al., 2023). Wetland degradation due to siltation, encroachment and pollution further reduces the availability of suitable cultivation areas. The crop is highly labour-intensive, especially during seed collection and post-harvest processing, where workers manually dive underwater and rely on traditional techniques, making the process risky, time-consuming and costly. Lack of mechanization and modern technology further constrains efficiency and scalability. Additionally, the processing of makhana, particularly the popping stage, requires specialized skills and often results in low recovery rates, leading to economic losses. Farmers also face market-related challenges such as price fluctuations, dominance of middlemen, inadequate storage and processing infrastructure and limited access to organized markets and export channels. Furthermore, there are gaps in research, availability of improved varieties, institutional support and access to credit and extension services. Environmental challenges, including climate change and declining wetland ecosystems, further exacerbate these issues. Collectively, these constraints hinder the growth potential of the makhana sector and call for integrated technological, institutional and policy interventions.

Breeding and Management Strategies for Resilience

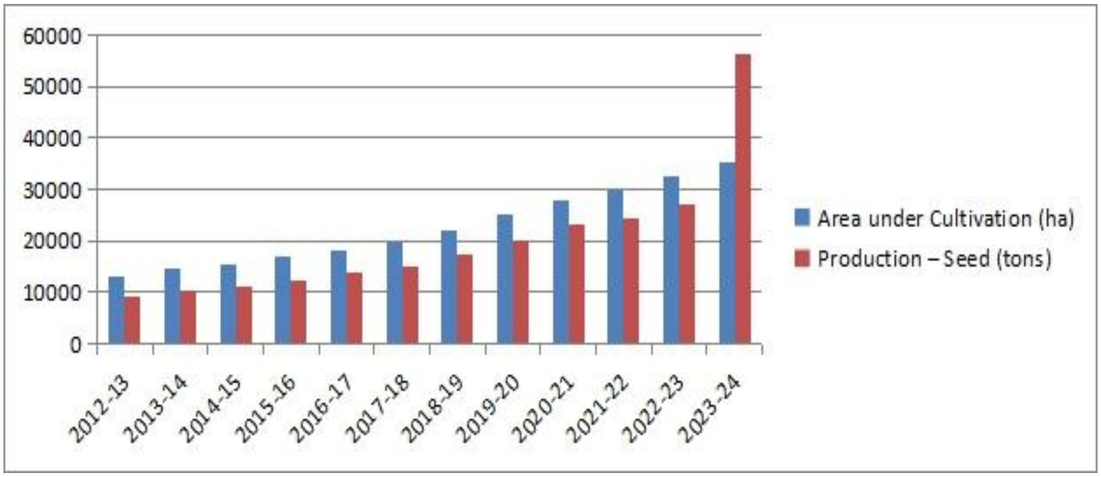
Conventional Breeding: ICAR-NRCM's Swarna Vaidehi variety yields 1.8 t/ha with flood tolerance, adopted in 40% of cultivation areas (Kumar et al., 2023). Selection for early maturity (100–120 days) suits flood-prone chaurs, while larger seeds (1.2–1.5 g) enhance market value (Jana et al., 2018).

Shallow-Water Farming: Shallow-water cultivation (0.3–0.5 m) in ponds increases yields by 20% and enables year-round production in Purnea (Mishra et al., 2023). It reduces flood damage and supports fish integration (Singh & Kumar, 2018).

Molecular Breeding: Marker-assisted selection (MAS) targets flood and heat tolerance, with QTLs for early flowering validated in Swarna Vaidehi (Kumar et al., 2023). CRISPR/Cas9 trials aim to boost seed yield but applications are experimental (Nair & Singh, 2024).

Wetland Management: Community dredging and pollution control restore wetlands, increasing cultivation area by 5% annually in Madhubani (Bihar Wetlands Atlas, 2023). GIS monitors encroachment, guiding conservation (Kumar et al., 2020).

Figure-2: Makhana Production Trends in North Bihar (2012–2024)



Source: Bihar Makhana at a Glance (2023), Directorate of Horticulture, Department of Agriculture, Government of Bihar, Patna

Policy Framework and Government Initiatives

The policy framework governing wetlands and makhana (Euryale ferox) cultivation in India is shaped by both international commitments and national initiatives aimed at conservation and livelihood enhancement. At the global level, the Ramsar Convention provides the guiding principles for the protection and sustainable use of wetlands, to which India is a signatory. At the national level, policies such as the National Plan for Conservation of Aquatic Ecosystems (NPCA) and Wetlands (Conservation and Management) Rules, 2017 focus on the identification, restoration and sustainable management of wetlands. In the context of Bihar, where makhana cultivation is highly concentrated, the state government has undertaken targeted initiatives such as the establishment of the Makhana Research Centre (Darbhanga) and promotion programs under agricultural development schemes to enhance productivity, improve processing techniques, and strengthen value chains. Financial and technical support is also extended through schemes promoting fisheries, horticulture and wetland-based farming systems. Furthermore, Bhola Paswan Shastri Agricultural College, (Bihar Agricultural University, Sabour) plays a critical role in research, extension, and capacity building related to makhana. Farmer Producer Organizations (FPOs) are increasingly being encouraged to organize small farmers, improve market access, reduce the role of intermediaries and enhance bargaining power. Together, these policy measures and institutional efforts aim to ensure the sustainable management of wetlands while promoting makhana cultivation as a viable and profitable livelihood option.

The Mallah community, 70% of farmers in Darbhanga and Madhubani, leverages traditional wetland knowledge but faces low literacy and credit access, limiting modern practice adoption (Singh & Kumar, 2018; Saurav & Chandran, 2023). Chaur cultivation involves community leasing (INR 10,000–15,000/ha annually), while private ponds in Purnea cost INR 20,000/ha (Mishra et al., 2023). Net returns average INR 50,000/ha for chaurs and INR 80,000/ha for ponds, but labor costs (60% of expenses) burden smallholders (Kumar et al., 2020). Only 30% of farmers access improved varieties like Swarna Vaidehi, with better availability in urban-adjacent Purnea than remote chaurs (Saurav & Chandran, 2023). Seed shortages restrict expansion (Jana et al., 2018). The Makhana Board (2022) promotes mechanization and training, increasing yields by 10% in pilot areas (Makhana Vikas Yojana, 2023). The GI tag for Mithila Makhana (2022) boosts exports, raising incomes by 15% (Bihar Wetlands Atlas, 2023). Wetland conservation under the National Wetland Inventory protects 10% of chaurs (Kumar et al., 2020).

Challenges and Opportunities

Despite its economic and ecological importance, makhana cultivation still faces significant research gaps that need to be addressed to enhance productivity and sustainability. One of the major gaps lies in the limited availability of improved, high-yielding and stress-tolerant varieties, as most farmers continue to rely on traditional germplasm. There is also a pressing need for mechanization, particularly in labour-intensive operations such as seed collection and popping, to reduce costs, improve efficiency and ensure worker safety. Climate-resilient cultivation practices are increasingly important in the context of changing rainfall patterns, temperature fluctuations and wetland degradation; which directly affect crop performance in regions North Bihar. Wetland degradation: Pollution and encroachment reduce cultivable area by 20% annually (Mishra et al., 2023). Erratic monsoons and floods lower yields by 20–30% (Pandey & Gupta, 2024). Limited mechanization, Socio-economic barriers, Low seed and credit access limit smallholder adoption (Jana et al., 2018). Manual harvesting and popping increase costs (Saurav & Chandran, 2023).Research should focus on developing adaptive water management strategies, improved agronomic practices, and integrated wetland management approaches. Additionally, there is considerable scope for expanding makhana into national and international markets due to its recognition as a nutritious “superfood”. However, this requires advancements in processing technology, quality standardization, branding, packaging, and value addition. The development of agro-industrial linkages, export-oriented infrastructure, and cold chain systems can further enhance profitability. Addressing these research gaps through coordinated efforts among scientific institutions, policymakers, and farmers will be crucial for transforming makhana cultivation into a modern, sustainable and globally competitive sector.

Opportunities

Recent advancements highlight several priority areas for strengthening makhana (Euryale ferox) cultivation through research, technology and policy support. The application of geospatial tools such as Geographic Information Systems (GIS) and remote sensing has emerged as an effective approach for suitability mapping, enabling the identification of optimal wetland areas for cultivation and resource planning (Nair & Singh, 2024). In addition, the development of climate-resilient varieties through targeted breeding programs is crucial to enhance tolerance against floods, heat stress and changing hydrological conditions, which are increasingly affecting production stability (Kumar et al., 2023). From a policy perspective, there is a need to strengthen institutional mechanisms by expanding initiatives such as the Makhana Board and leveraging Geographical Indication (GI) tag benefits to improve branding, market access and farmer incomes under schemes like Makhana Vikas Yojana (2023). Furthermore, promoting value addition through the development of processed makhana-based products, including ready-to-eat snacks and nutraceuticals, can significantly enhance income generation and create agro-industrial opportunities (Saurav & Chandran, 2023). Collectively, these interventions can contribute to a more resilient, technology-driven and market-oriented makhana sector.

Future Directions

Recent strategies for strengthening makhana (Euryale ferox) cultivation emphasize the integration of advanced technologies with sustainable resource management. Geospatial analysis using GIS and high-resolution satellite data such as Sentinel-2 offers significant potential for real-time monitoring of wetlands, crop health and suitability mapping. Such tools can support evidence-based planning and help target expansion of makhana cultivation to nearly 50,000 hectares in suitable regions (Nair & Singh, 2024). Alongside this, climate-resilient breeding approaches are gaining importance, with modern techniques like Marker-Assisted Selection (MAS) and CRISPR/Cas9 being explored to develop varieties tolerant to floods and heat stress, thereby ensuring yield stability under changing climatic conditions (Kumar et al., 2023).

Mechanization and infrastructure development are equally critical for improving efficiency and reducing production costs. The introduction of low-cost harvesting devices and improved popping machines can significantly reduce labour dependency and lower operational costs by up to 30%, making the sector more economically viable (Saurav & Chandran, 2023). At the same time, wetland conservation remains central to sustaining makhana cultivation, with initiatives aiming to restore around 20,000 hectares of degraded wetlands by 2030, as highlighted in the Bihar Wetlands Atlas (2023). Such restoration efforts will not only enhance ecological health but also expand the resource base for cultivation.

Market-oriented interventions and community empowerment further strengthen the future prospects of the sector. Leveraging the Geographical Indication (GI) tag of makhana can enhance branding and help increase exports to an estimated USD 10 million by 2030 under initiatives like the Makhana Vikas Yojana (2023). Additionally, capacity-building programs targeting traditional communities, particularly Mallah farmers, through training in scientific cultivation and processing practices can improve productivity by approximately 15% (Singh & Kumar, 2018). Together, these technological, ecological, and socio-economic interventions provide a comprehensive pathway for transforming makhana cultivation into a resilient, sustainable and high-value agro-based enterprise.

Conclusion

Makhana cultivation in North Bihar’s wetlands highlights the synergy of geography, agriculture and sustainability. Spatial analyses show concentrated production in Darbhanga, Madhubani and Purnea; driven by wetland types, monsoon hydrology and alluvial soils. Innovations like Swarna Vaidehi and shallow-water farming enhance flood resilience, while the Mallah community's role and barriers like seed access shape socio-economic dynamics. The Makhana Board and GI tag boost incomes and exports, but wetland degradation, climate variability and limited mechanization persist. Future efforts should integrate GIS, climate-resilient breeding and conservation to expand cultivation across 50,000 ha. This review underscores makhana's potential for food security and livelihoods in North Bihar's flood-prone landscapes, emphasizing geographical approaches for sustainable agriculture.

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