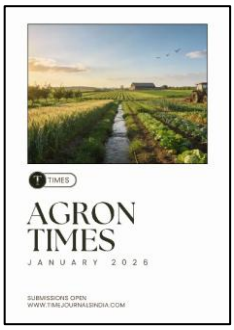
Review Article



Opportunities and Challenges of Makhana Farming in Punjab

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ABSTRACT

Makhana (*Euryale ferox* Salisb.), commonly known as fox nut or gorgon nut, is a high-value aquatic crop with considerable potential for agricultural diversification, value addition, and rural entrepreneurship. Although traditionally cultivated in the wetlands of Bihar and other eastern Indian states, growing interest in alternative and high-income crops has generated attention toward its possible introduction in Punjab. However, several agronomic, environmental, technical, and economic challenges limit its large-scale adoption in the state. These include the scarcity of natural wetland ecosystems, concerns regarding water availability and sustainability, climatic suitability constraints, limited access to quality planting material, labour and skill shortages, weak market linkages, and inadequate region-specific research and extension support. In addition, high establishment costs, production risks, and the absence of organized value chains may restrict commercialization. Nevertheless, recent advances in field-based cultivation techniques, mechanized harvesting and processing technologies, and integrated farming approaches offer new opportunities for adaptation beyond traditional growing regions. Future research should focus on agro-climatic suitability assessment, development of location-specific production technologies, water-use efficiency, varietal improvement, value-chain development, and economic feasibility analysis. With appropriate research support, institutional interventions, and market infrastructure, makhana has the potential to emerge as a niche diversification crop contributing to sustainable agriculture, income enhancement, and agro-industrial development in selected regions of Punjab.

KEYWORDS: Makhana, Punjab, Crop diversification, Aquatic crops, Value addition, Mechanization

1. INTRODUCTION

Makhana (*Euryale ferox* Salisb.), commonly known as fox nut or gorgon nut, has long been valued in Indian cuisine and traditional medicine owing to its rich nutritional composition and health-promoting properties. In recent years, it has gained global recognition as a functional food and emerging superfood because of its high carbohydrate and protein content, low fat levels, and presence of bioactive compounds with potential health benefits (Jha *et al.*, 2019; Kumar *et al.*, 2022). The increasing worldwide demand for plant-based, gluten-free, and nutritious snack foods has further enhanced the commercial importance of makhana in domestic and international markets (Kumar *et al.*, 2022; FAO, 2023).

Traditionally, makhana has held considerable cultural and religious significance in India, particularly during fasting periods and religious observances, where roasted makhana is widely consumed as a light, nutritious, and ready-to-eat snack (Jha et al., 2019; Singh & Das, 2024). However, over the past decade, the crop has evolved beyond its traditional role and emerged as a globally recognized superfood and functional food ingredient. The increasing demand for healthy snacks, coupled with innovations in processing, packaging, and product development, has expanded its market reach and commercial importance (Kumar et al., 2022; APEDA, 2024).

India is the world's leading producer of makhana, with Bihar accounting for nearly 85–90% of the country's production and serving as the principal centre for cultivation, processing, and trade (Kumari *et al.*, 2024). The crop is popularly known as the "Black Diamond" of Bihar because of its high economic value and substantial contribution to rural livelihoods. Approximately five lakh families in Bihar are directly involved in makhana cultivation, harvesting, processing, and marketing activities, highlighting its socio-economic importance in the region. Furthermore, about 7,500–10,000 tonnes of popped makhana are marketed annually from Bihar (ICAR, 2019). The recent award of a Geographical Indication (GI) tag to "Mithila Makhana" has further strengthened its market identity and export potential (GoI, 2022).

Its low-fat content, high nutritional quality, and versatility in roasted, flavored, and value-added products have enabled makhana to compete with premium dry fruits and other healthy snack alternatives (GoI, 2022; Kumar et al., 2022; Singh & Das, 2024). The expansion of modern retail networks and e-commerce platforms has accelerated market penetration, while

increasing consumer awareness of healthy eating has facilitated the export of Indian makhana products to countries such as the United States, the United Kingdom, Canada, Australia, and the United Arab Emirates (APEDA, 2024).

Against this backdrop, makhana is emerging as a potential diversification crop for Punjab. With increasing concerns over groundwater depletion, declining resource-use efficiency, and the sustainability of the rice–wheat production system, makhana offers opportunities for diversification, value addition, and utilization of waterlogged and pond-based ecosystems. Recent advances in cultivation practices and mechanized processing technologies further enhance its prospects for adoption in non-traditional regions such as Punjab (Kumari *et al.*, 2024; ICAR, 2019).

2. OPPORTUNITIES OF MAKHANA FARMING IN PUNJAB

Makhana has emerged as a promising high-value crop with significant potential for agricultural diversification in Punjab. The state's agriculture is heavily dependent on the rice–wheat cropping system, which has resulted in groundwater depletion, soil degradation, and declining farm profitability. Introduction of makhana can provide an alternative enterprise, particularly in low-lying, waterlogged, and pond-based ecosystems where conventional crops often perform poorly (Kumari *et al.*, 2024).

Punjab possesses numerous village ponds, canal-irrigated depressions, and seasonal waterlogged areas that can be utilized for makhana cultivation (GoP, 2023). Recent advances in field-based cultivation techniques and improved varieties have expanded the scope of makhana production beyond its traditional growing regions of Bihar, making its adoption feasible in suitable agro-ecological zones of Punjab (Kumari *et al.*, 2024).

The crop offers attractive economic opportunities due to increasing domestic and international demand for healthy snacks and functional foods. Makhana is valued for its high carbohydrate and protein content, low fat levels, and antioxidant properties, leading to rapid market expansion and premium prices. The growing consumer preference for nutritious and plant-based foods further enhances its commercial potential (ICAR-CIPHET, 2025a). A major opportunity for Punjab lies in value addition and processing. ICAR-CIPHET, Ludhiana, has developed and commercialized mechanized makhana processing technologies, including preliminary roasting machines, popping machines, grading systems, fat-free flavored makhana, makhana puffs, gluten-free pasta, and makhana kheer mix. These technologies can support the establishment of processing industries, generate rural employment, and promote entrepreneurship among farmers, FPOs, and agri-startups in the state (ICAR-CIPHET, 2025a).

The presence of premier institutions such as ICAR-CIPHET, Ludhiana, and Punjab Agricultural University provides a strong foundation for research, technology transfer, capacity building, and skill development related to makhana cultivation and processing. Such institutional support can accelerate the development of a sustainable makhana value chain in Punjab.

Overall, makhana farming offers opportunities for crop diversification, productive utilization of aquatic resources, value addition, entrepreneurship development, export promotion, and sustainable income generation, making it a potential component of climate-resilient and resource-efficient agriculture in Punjab (Kumari *et al.*, 2024; ICAR-CIPHET, 2025b).

3. CHALLENGES OF MAKHANA FARMING IN PUNJAB

3.1. Limited Availability of Suitable Aquatic Ecosystems

The scarcity of extensive natural wetlands represents a major constraint to the large-scale adoption of makhana cultivation in Punjab. Traditionally, the crop is grown in ponds, oxbow lakes, marshes, and other stagnant water bodies of eastern India, particularly Bihar, where abundant aquatic resources and favorable agro-climatic conditions support its cultivation (Jana, 2018; Khadatkar et al., 2020). In contrast, Punjab's agricultural landscape is dominated by irrigated field-crop production systems, with relatively limited wetland resources suitable for conventional pond-based makhana farming (GoP, 2023).

Consequently, commercial cultivation may require the creation of artificial ponds, lined reservoirs, or field-based production systems capable of maintaining shallow-water conditions throughout the crop cycle (ICAR-NRCM, 2022a). Such infrastructure development increases establishment costs and may pose economic challenges, particularly for small and marginal farmers. Nevertheless, recent advances in field-based cultivation technologies suggest that makhana can be successfully grown under controlled shallow-water conditions, offering opportunities for pilot-scale adoption in selected waterlogged and canal-irrigated areas of Punjab (ICAR-NRCM, 2022b).

3.2. Water Requirement and Groundwater Sustainability

As an aquatic crop, makhana requires standing water during much of its growth period, making reliable water availability a prerequisite for successful cultivation (Khadatkar et al., 2020; ICAR-NRCM, 2022a). This requirement is particularly significant in Punjab, where intensive rice–wheat cultivation has led to severe groundwater depletion and declining water tables across large parts of the state (CGWB, 2024; Sidhu et al., 2020).

Therefore, the expansion of makhana cultivation should be restricted to areas with existing water resources, such as village ponds, seasonal waterlogged lands, drainage-affected zones, farm reservoirs, and canal-irrigated depressions, rather than relying on groundwater extraction (ICAR-NRCMa, 2022a; Kumar et al., 2024). Integration with aquaculture and pond-based farming systems may further improve water-use efficiency and overall farm profitability while minimizing environmental impacts (ICAR, 2019).

3.3. Agro-Climatic Suitability Constraints

Makhana is traditionally cultivated under the humid subtropical conditions of eastern India, characterized by high humidity, warm temperatures, and abundant water availability (Jana, 2018; ICAR-NRCM, 2022b). Punjab, however, experiences a semi-arid to sub-humid climate with high summer temperatures, lower atmospheric humidity, and elevated evapotranspiration rates. Such conditions may adversely affect flowering, seed development, and yield formation while increasing water losses from cultivation systems (Khadatkar et al., 2020).

Climate change further compounds these challenges through increasing temperature extremes, heat waves, and irregular rainfall patterns across north-western India (IPCC, 2023; Singh et al., 2023). Therefore, comprehensive agro-climatic suitability assessments, pilot-scale evaluations, and adaptive management strategies are essential before recommending large-scale commercial cultivation in Punjab.

3.4. Limited Availability of Quality Planting Material

The availability of quality planting material remains a significant bottleneck for makhana cultivation in non-traditional regions. Since commercial production is concentrated largely in Bihar, access to genetically pure, viable, and disease-free seed is often limited outside the traditional cultivation belt (Kumar et al., 2020). Moreover, most available germplasm has been developed and evaluated under eastern Indian wetland conditions, and its adaptability to Punjab's agro-climatic environment remains uncertain (Khadatkar and Gupta, 2023).

The absence of organized seed multiplication programs, certified seed systems, and local nurseries further restricts seed availability and increases procurement costs. Establishing regional seed production and distribution networks, along with the development of climate-resilient varieties adapted to Punjab conditions, will be crucial for successful crop introduction (Kumar et al., 2020).

3.5. Labour and Skill Constraints

Makhana cultivation involves several labour-intensive operations, including crop establishment, harvesting, seed collection, processing, grading, and value addition (Khadatkar et al., 2020). Harvesting is particularly demanding because mature seeds are collected from aquatic environments, traditionally requiring considerable physical effort and specialized skills. In addition, post-harvest operations such as roasting, tempering, and popping require technical expertise that is largely concentrated in traditional makhana-growing regions (Mir et al., 2021).

Punjab currently lacks substantial experience in commercial makhana production and processing, resulting in limited availability of trained manpower and technical know-how (ICAR, 2019). Therefore, farmer training, demonstration programs, and technology-transfer initiatives will be essential to facilitate successful adoption.

To address labour constraints, mechanized harvesting technologies, including suction-based harvesters and diver-support systems, have been developed through collaborations involving the Regional Centre for Makhana (RCM), Darbhanga, and agricultural engineering institutions (Khadatkar and Gupta, 2023). Furthermore, ICAR-CIPHET, Ludhiana, has developed several processing mechanisms viz., threshing, cleaning, popped makhana grading machine (Fig. 1a), drying, primary roasting machine (Fig. 1b), and popping operations. These technologies have substantially reduced processing drudgery, improved product quality, and shortened processing time from approximately 2–3 days to about 20 hours (ICAR, 2019).

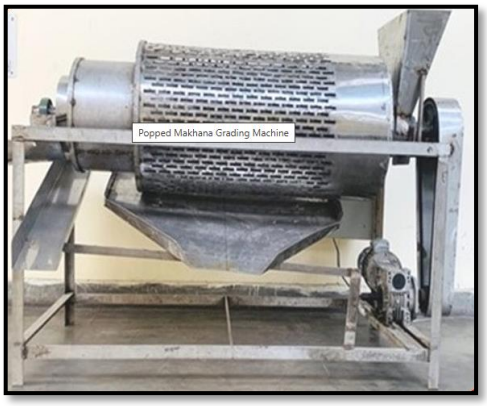

Fig. 1. Images of the popped makhana grading machine (**Fig. 1a**) and primary roasting machine (**Fig. 1b**).

The Regional Station of ICAR-CIPHET at Abohar, Fazilka, has also initiated demonstration trials of makhana cultivation (**Fig. 2**) in Punjab, providing valuable field-level insights into the crop's adaptability and future commercialization potential under local conditions.

Fig. 2. Images of demonstration trials of makhana cultivation at the Regional Station of ICAR-CIPHET at Abohar, Fazilka (Photograps taken during 18th June 2026).

3.6. Processing, Mechanization and Supply Chain Constraints

The commercial success of makhana cultivation depends not only on crop production but also on efficient post-harvest processing, value addition, and market integration. Makhana processing involves a series of specialized operations, including drying, tempering, roasting, popping, grading, sorting, packaging, storage, and distribution, all of which influence product quality, marketability, and economic returns (Jana, 2018; Khadatkar et al., 2020; Mir et al., 2021). Maintaining appropriate moisture content, ensuring uniform roasting and popping, and

adopting proper storage and packaging practices are critical for achieving desirable product characteristics such as expansion ratio, whiteness, texture, shelf life, and consumer acceptance.

Although Punjab possesses a well-developed food-processing sector, specialized infrastructure and technical expertise for commercial-scale makhana processing remain limited. The absence of dedicated processing facilities, quality-control systems, storage infrastructure, and organized supply chains may constrain the development of a competitive makhana industry. Farmers may face difficulties in accessing processing services, value-addition opportunities, and premium domestic or export markets, thereby reducing overall profitability (Khadatkar et al., 2020; Mir et al., 2021).

Mechanization offers an effective solution to many of these constraints. Traditionally, makhana processing has been labour-intensive and highly dependent on skilled workers for roasting, grading, and popping operations. To address these challenges, ICAR-CIPHET has developed several innovations, including the makhana popping machine, popped makhana grading machine (Fig. 1a), and makhana primary roasting machine (Fig. 1b). Further, to strengthen opportunities for commercial-scale processing and value addition, ICAR-CIPHET has developed different value-added products, viz., makhana kheer mix (Fig. 3a), fat-free flavored makhana (Fig. 3b) and makhana puffs (Fig. 3c).

Fig. 3. Images of Makhana kheer mix (**Fig. 3a**), fat-free flavored makhana (**Fig. 3b**) and makhana puffs (**Fig. 3c**).

Punjab benefits from the presence of ICAR-CIPHET and its Regional Station at Abohar, which provide a significant institutional advantage for future development of a makhana value chain. Besides technology development, these institutions can support adaptive research, demonstration trials, farmer training, entrepreneurship development, skill enhancement, and technology transfer activities. Such interventions will be particularly important during the initial stages of adoption, when local expertise in makhana cultivation and processing is limited.

Despite these technological advancements, weak market linkages remain a major challenge. Unlike Bihar, Punjab currently lacks a well-established network of producers, processors, traders, and exporters dedicated to makhana. The absence of organized procurement systems, aggregation mechanisms, and reliable buyer networks creates uncertainty regarding marketing and price realization. Limited farmer awareness, inadequate market intelligence, and insufficient consumer outreach further restrict market development (Kumar et al., 2020; Khadatkar and Gupta, 2023).

Strengthening farmer producer organizations (FPOs), cooperatives, processing clusters, and public–private partnerships will be essential for improving value-chain efficiency and economies of scale. Investments in local processing units, quality certification, branding, packaging, market intelligence systems, and e-commerce linkages can significantly enhance market access and profitability. The development of an integrated production–processing–marketing framework will therefore be critical for realizing the full commercial potential of makhana as a high-value diversification crop in Punjab (ICAR, 2019; Kumar et al., 2020).

3.7. High Initial Investment and Production Risks

High establishment costs and production uncertainties represent significant barriers to the adoption of makhana cultivation in Punjab. Unlike conventional field crops, makhana requires investments in pond development, water-management infrastructure, quality seed procurement, and specialized cultivation and processing equipment. These costs may be particularly burdensome for small and marginal farmers with limited access to credit and financial resources (Kumar et al., 2020).

Production risks are further amplified by the limited experience of Punjab farmers with makhana cultivation. Uncertainties regarding varietal adaptation, water management, pest and disease incidence, yield performance, and economic returns may discourage farmers from shifting away from established cropping systems. In addition, the crop's dependence on suitable aquatic conditions and effective post-harvest management exposes growers to climatic, operational, and market-related risks (Jha et al., 2018; Khadatkar and Gupta, 2023).

To reduce these uncertainties, policy support in the form of subsidies, low-interest credit, crop insurance, infrastructure assistance, and pilot-scale demonstration projects may be required. Strengthening technical guidance, market linkages, and processing facilities can further improve farmer confidence and facilitate wider adoption of the crop.

3.8. Limited Region-Specific Research and Extension Support

The lack of region-specific research and extension support remains a critical challenge for the sustainable expansion of makhana cultivation in Punjab. Most available production

technologies and management recommendations have been developed under the wetland ecosystems of Bihar and may not be directly applicable to Punjab's agro-climatic conditions (Kumar et al., 2020).

Important aspects such as varietal suitability, nutrient management, water requirements, planting density, pest management, harvesting methods, and economic feasibility require systematic evaluation under local conditions. Similarly, extension personnel and farmers currently possess limited experience with commercial makhana production and processing, restricting access to technical knowledge, demonstration programs, and advisory services (Jha et al., 2018; Khadatkar and Gupta, 2023).

Future efforts should focus on adaptive research, multi-location trials, demonstration farms, capacity-building programs, and stronger collaboration among ICAR institutions, Punjab Agricultural University, extension agencies, FPOs, and private-sector stakeholders. The generation and dissemination of location-specific production technologies will be essential for reducing uncertainty and supporting the successful integration of makhana into Punjab's agricultural diversification strategy.

3.9. Weak Market Linkages and Value Chains

Weak market linkages and underdeveloped value chains remain major constraints to the commercialization of makhana cultivation in Punjab. Unlike Bihar, where well-established networks of producers, processors, traders, and exporters support the industry, Punjab currently lacks organized procurement systems, dedicated marketing channels, and reliable buyer networks, creating uncertainty regarding market access and profitability (Kumar et al., 2020).

The limited availability of local processing and value-addition facilities further restricts the sector. Farmers may be compelled to sell raw produce or transport it to distant processing centers, increasing costs and reducing returns. In addition, fragmented production, inadequate market information, and limited participation of farmer producer organizations (FPOs) and cooperatives weaken value-chain efficiency and bargaining power (Jha et al., 2018; Khadatkar and Gupta, 2023).

Strengthening processing infrastructure, market linkages, FPOs, public–private partnerships, and value-addition enterprises will be essential for improving profitability and supporting the sustainable development of a competitive makhana industry in Punjab (Kumar et al., 2020).

4. FUTURE RESEARCH AND DEVELOPMENT PRIORITIES FOR PUNJAB

Makhana cultivation in Punjab is still at an exploratory stage and requires comprehensive scientific evaluation before large-scale commercialization can be recommended. Although the crop shows promise as a high-value diversification option, several agronomic, environmental, economic, and technological uncertainties need to be addressed through systematic research and field validation (ICAR-NRCMa, 2022b; Khadatkar et al., 2020).

The following research and development priorities should receive particular attention:

- Agro-climatic suitability assessment to identify regions with favorable environmental conditions for sustainable makhana cultivation.
- Identification of suitable cultivation zones, including village ponds, waterlogged areas, canal-irrigated depressions, and other aquatic ecosystems.
- Evaluation of water-resource availability and management strategies to ensure environmentally sustainable production without increasing pressure on groundwater resources.
- Development of location-specific production technologies, including crop establishment methods, nutrient management, pest management, and harvesting practices.
- Multi-location adaptive research trials and demonstration projects to assess crop performance, productivity, profitability, and environmental sustainability under Punjab conditions.
- Development and evaluation of improved cultivars with higher yield potential, stress tolerance, and adaptability to north-western Indian conditions (Jana, 2018; Kumar et al., 2024).
- Research on integrated farming systems, particularly fish–makhana and pond-based production models, to improve resource-use efficiency and farm income.
- Advancement of mechanized harvesting and processing technologies to reduce labour requirements, improve product quality, and enhance commercial viability (ICAR, 2019; ICAR-CIPHET, 2024a).
- Capacity building and extension programmes for farmers, entrepreneurs, and extension personnel through training, demonstrations, and exposure visits.
- Development of value chains, processing infrastructure, and market linkages to support commercialization and value addition.

Institutions such as Punjab Agricultural University, ICAR institutes, Krishi Vigyan Kendras (KVKs), and state agricultural departments can play a vital role in conducting adaptive research, technology validation, and extension activities. Collaborative efforts involving research organizations, government agencies, farmer-producer organizations (FPOs), and agro-processing industries will be essential for developing a sustainable makhana value chain in Punjab.

Overall, evidence generated through multi-location trials, economic feasibility studies, and long-term sustainability assessments will determine the future role of makhana as a diversification crop in Punjab. With appropriate research support, technological innovation, and market development, makhana has the potential to emerge as a niche high-value crop contributing to agricultural diversification, rural entrepreneurship, and sustainable livelihood generation in selected regions of the state (ICAR-NRCM, 2022a; Khadatkar et al., 2020; ICAR-CIPHET, 2024b).

5. CONCLUSION

Makhana (*Euryale ferox* Salisb.) has considerable potential as a high-value diversification crop for Punjab, offering opportunities for income enhancement, value addition, and rural entrepreneurship. Recent advances in field-based cultivation, mechanized processing, and integrated farming systems have improved its prospects beyond traditional growing regions.

However, challenges related to water management, climatic suitability, quality planting material, processing infrastructure, market development, and technical expertise must be addressed before large-scale adoption can be recommended.

Therefore, makhana should be promoted as a niche crop in suitable water-abundant and waterlogged areas rather than as a replacement for existing cropping systems. Future success will depend on location-specific research, pilot-scale demonstrations, capacity building, value-chain development, and institutional support. With appropriate technological, policy, and market interventions, makhana can contribute to sustainable agricultural diversification, enhanced farm profitability, and rural livelihood development in Punjab.

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