



Makhana cum Fish Farming: An Integrated Production System for Livelihood Improvement and Sustainable Aquatic Resource Utilisation

Gajjela Maheshwari^{*1}, P. Shanthanna²

¹ ICAR- Central Institute of Fisheries Education, Mumbai 400061, India

² College of Fishery Science, Andhra Pradesh Fisheries University, Muthukur, SPSR Nellore, Andhra Pradesh

*Corresponding author Email: maheshwarigajjela08@gmail.com

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Abstract— Aquaculture is a major contributor to global food and nutritional security, providing high-quality animal protein. However, increasing pressure on land and freshwater resources necessitates production systems that enhance output through efficient utilization of existing resources. Integrated farming provides a pathway to achieve this by combining biologically compatible production components to improve resource-use efficiency, nutrient cycling and overall system productivity. Makhana (*Euryale ferox* Salisb.) and fish farming represents a promising aquatic integrated production system in which an economically important aquatic crop and fish are produced within the same water body. Makhana provides a nutrient-rich, low-fat food product with increasing commercial value, whereas fish contributes high-quality protein and essential micronutrients, thereby providing complementary nutritional and economic outputs. Integration can utilize spatial and ecological niches within the water body, facilitate nutrient recycling and generate additional fish production and income without requiring separate land and water resources. This approach is particularly relevant for waterlogged and underutilized landscapes where conventional agriculture is constrained. This review evaluates the biological basis, production practices, resource-use efficiency, productivity, economic potential and livelihood significance of makhana–fish farming, highlighting its potential as a sustainable and resource-efficient model for integrated aquatic production.

Keywords— *Euryale ferox*, makhana–fish farming, integrated aquaculture, aquatic crop–fish integration, resource-use efficiency, nutrient recycling, sustainable aquaculture, livelihood diversification.

I. INTRODUCTION

Aquaculture has emerged as one of the fastest-growing food production sectors globally, contributing significantly to food and nutritional security, employment generation and rural livelihood improvement. With the continuous increase in global population, the demand for animal protein, particularly fish, is rising rapidly. At the same time, land and fresh water resources are becoming

increasingly limited and under pressure due to urbanization, industrialization and climate change. This imbalance between rising demand and limited natural resources necessitates the development of more efficient, sustainable and resource-optimized production systems (FAO, 2026).

Conventional monoculture systems, both in agriculture and aquaculture, often utilize only a fraction of the available ecological potential of a

production unit. In aquaculture ponds, for example, nutrients, water area and biological productivity are not fully exploited when only a single species is cultured. This has led to the development of different systems like poly, composite, mixed and integrated farming systems (IFS), which aim to combine two or more compatible farming components in a synergistic manner. Integrated farming systems improve resource-use efficiency by recycling nutrients, reducing waste, enhancing productivity per same unit area and diversifying farm income (Gill et al., 2001; Rani et al., 2026).

Integrated fish farming is the practice of growing fish alongside other organisms. The sequential linkage between two or more farming systems can be defined as an integrated fish farming system (FAO, 1986). Different types of integrated farming systems have been developed and practiced across the world and also in India. The integrated fish farming system is mainly two types, Livestock cum fish integrated farming system and Agri aquaculture-based integrated system. These systems are based on the principle of circular resource utilization, where outputs from one component serve as inputs for another, thereby reducing external input dependency and improving overall system productivity (Edwards et al., 1988; Rath, 2000; Kumar & Bhatt, 2016).

According to (Pillay 1990), the fundamental principles of integrated farming include conservation, which includes full utilization of agricultural wastes and the use of the synergistic effects of related farm activities. It is based on the notion that "there is no waste" and that "waste is merely a misdirected resource that can become a valuable material for another product" (FAO, 1977).

In Asia aquatic plant cultivation and fish farming were combined, according to written accounts from the first and second centuries B.C. (Nash 2010). Among them, Fish-Cum-Paddy Culture has dates back history probably originated about 2000 years ago in ancient China and gradually this system spread to many other countries: Indonesia, Vietnam, Thailand and India (Halwart and Gupta, 2004). Other than Fish-Cum-Paddy, the integration of aquatic crops with fish culture represents a relatively less explored but highly promising approach. In this context, makhana (*Euryale ferox* Salisb.), an important aquatic cash crop, offers significant potential for integration with fish

farming. Makhana is traditionally cultivated in stagnant ponds, wetlands and waterlogged areas, mainly grown in Bihar, Assam, West Bengal, Tripura and Odisha (Verma et al., 2008). In Bihar alone over the past decade, makhana cultivation has expanded from 13,000 hectares in 2012–13 to over 35,000 hectares in 2021–22 (Government of Bihar, 2024). About 7,500 to 10,000 tonnes of popped Makhana are sold every year from Bihar, which contributes nearly 80–85% of India's total production (Sinha and Kumar, 2023).

From a nutritional perspective, makhana is rich in carbohydrates and contains moderate protein with very low-fat content. Raw seeds approximately contains 76.9% carbohydrate, 12.8% moisture, 9.7% protein, 0.9% phosphorous, 0.5% minerals, 0.1% fat, 0.02% calcium and 0.0014% iron whereas, popped Makhana contains 84.9% carbohydrate, 4% moisture, 9.5% protein and 0.5% fat. Its calorific value ranges from 328–362 kcal/100 g, making it a healthy, low-fat snack with growing domestic and international demand (Khadatkar et al., 2020). It also has well medicinal value and supports cottage industry (Verma et al., 2010) and recommended for treatment regarding respiratory, circulatory, digestive, excretory and reproductive systems (Shankar et al., 2010).

Despite its importance, traditional makhana production is highly labour intensive, especially during harvesting and post-harvest processing. This creates an opportunity for system diversification through integration with fish culture. Makhana–fish farming allows simultaneous production of plant and animal protein from the same water body, thereby improving overall productivity, income generation and resource-use efficiency. Recent studies have shown that such integrated systems can generate significantly higher net returns compared to sole makhana cultivation (Singh et al., 2021; Khadatkar et al., 2020).

In this context, understanding aquaculture development, the need for resource-efficient production systems, the principles of integrated farming, and the role of makhana–fish integration is essential for developing sustainable aquatic production models.

II. MAKHANA BIOLOGY, HABITAT AND DISTRIBUTION

Makhana is a popped expanded kernel of Gorgon nut (Jha & Prasad, 1990; 1996) (*Euryale ferox*), an aquatic crop that grows in stagnant water bodies such as ponds, lakes, and swamps which belongs to the Nymphaeaceae family. It grows well in tropical and sub-tropical climates and is mainly distributed in South-East and East Asian countries like India, China, Nepal, Bangladesh, Japan, Russia, and Korea (Sinha, 2023). While commonly known as makhana in India, it is often referred to as foxnuts, prickly water lily seeds or lotus seeds and is known by other names in different languages. However, the accurate term for makhana is “gorgon nut” and not “fox nuts” or “lotus seeds”, which are misleading, as makhana is botanically unrelated to either lotus or foxnuts (Wardhan et al, 2025).

It is mainly distributed in South-East and East Asian countries viz., India, China, Nepal, Bangladesh, Japan, Russia, Korea etc. and widely prevalent in tropical and sub-tropical regions accomplished with a humid to subhumid environment. In India, its cultivation is limited to a few states like; Bihar, Assam, Manipur, West Bengal, Tripura and Odisha (Kumar et. al, 2011a).

In India, it is also considered as the “food of god”, as it is mostly used as “prasada” during religious offering. It is normally grown in stagnant water bodies of 0.2–2.0 m depth like ponds, low depressions, lakes, etc. (Khadatkar et al., 2020).

A single Makhana plant produces about 8–9 leaves as well as flowers arranged alternately and intermingled together. The leaves are large, round, floats on water and size ranges from 0.5 to 2.0m. The upper surface of leaf is green while underside is purple in colour and covered with sharp prickles/thorns. The roots are long, fleshy and fibrous in nature and generally in 2–3 clusters with number of air pockets and the seeds are round and lumpy of about 0.5–1.5cm in diameter. Produces a bright purple flower which later changes to fruit (50–80mm in size). Each fruit consists of 8–15 seeds. The fresh seeds are soft, lumpy and surrounded by arils which floats on water. It later decomposes after 3–4 days and turned into a black colour ball called “gurries” of about 10–20mm diameter. The

entire plant is edible except leaf viz. flower, fruit, seed and root in different part of the country as per tradition (Khadatkar et al., 2020).

It's high Essential Amino Acid Index (EAAI) of 89-93 per cent and a high Chemical Score (CS) make it comparable to fish, making it an excellent plant-based protein source (Sinha, 2023).

In August, 2022 the Government of India had awarded the Geographical Indication (GI) tag to Mithila Makhana, a move which is expected to help growers get the maximum price for their premium produce.

III. VARIETIES OF MAKHANA

Besides traditional varieties, makhana has mainly two improved varieties namely; Swarna Vaidehi and Sabour Makhana-1. The yield level of the traditional variety is 1.7 to 1.9 tons/hectare of makhana seeds whereas that of Swarna Vaidehi or Sabour Makhana-1, it is 3.0 to 3.5 tons/hectare of makhana seed. Swarna Vaidehi which is the first ever variety of makhana released in India by ICAR Research Complex for Eastern Region, Patna for Bihar, Assam, Chhattisgarh and Odisha on 15th November 2013. This variety developed through pure line selection has the production potential of 2.8 to 3.0 ton/hectare in farmer's field, which is almost two-fold higher than the productivity of traditional cultivars (ICAR-RCER, 2013). Sabour makhana -1 was developed at Bhola Paswan Shastri Agricultural College, Purnea of Bihar Agricultural University, Sabour, Bhagalpur, Bihar and was released on 29th August, 2016. It is characterized by large spherical leaves, dark purple flowers, medium size fruits and small oval seeds with a very thin seed coat. It is a high yielding (3.2 to 3.5 tons/hectare) variety with good quality makhana pop recovery (55-60%). It is a potential variety to get higher net return from underutilized and neglected water logged areas without eroding natural resources (Kumar et al., 2020).

IV. MAKHANA CULTIVATION

The cultivation of Makhana is carried out using two primary methods: the pond system method (PSM) and the field system method (FSM)

Table 1: Comparison of Makhana crop in pond and agricultural field.

Parameter	Pond	Agricultural field
Water requirement	1.2-1.8 m	0.3 m
Seed requirement	> 80kg/ha	20kg/ha
Source of water	Natural water as perennial water bodies	Irrigation water or any other perennial source of water
Fertilizer application	Not possible due to high depth of standing water	Can be applied very easily Before and after transplanting
Intercultural operation	Difficult	Easily done
No. of crop/yr	1-2	3
Crop duration	Long to very long (8-10 months)	Short (4-5 months)
Integration of cropping system	With water chestnut	With rice, wheat, berseem, etc
Yield	1.8-2.0 t/ha	2.6-3.0 t/ha 200-300
Cropping intensity (%)	100	200-300
Feasibility of harvesting	It can be done only by trained labourers	Very simple. It can be done even by unskilled labourers
Scope of horizontal expansion of Makhana cultivation	Limited scope because it would depend upon the availability of natural water bodies	Wide scope

[modified from Khadatkar et al. (2020) and Mahawar (2016)]

V. INTEGRATION OF FISH WITH MAKHANA

Although makhana cultivation can generate substantial returns, the aquatic production environment remains underutilized when the crop is cultivated alone. Integrating fish culture with makhana provides an opportunity to utilize the same water body for producing both crops simultaneously, thereby increasing overall productivity and profitability. The system can also reduce labour and fish production costs, as decomposing makhana leaves contribute organic matter and nutrients that support plankton and other natural fish food organisms, reducing dependence on supplementary feed. Fish, in turn, utilize plankton and other natural food resources associated with the makhana ecosystem, while their excreta contribute additional nutrients to the pond. Earlier studies reported higher plankton abundance and nutrient enrichment of pond soil under integrated makhana–fish systems. However, excessive makhana coverage may restrict

air–water exchange and light penetration, resulting in reduced dissolved oxygen. Therefore, fish integration should be viewed as biological intensification of the existing aquatic production system, with the objective of obtaining additional fish production while maintaining acceptable makhana yield and water quality (Verma et al., 2008; Raut et al., 2025).

Makhana–fish integration is not a new concept, with earlier studies by Dehadrai (1972) and Verma et al. (1996) reporting approximately 1.2–3.6 t ha⁻¹ catfish production. Catfishes are particularly suitable because their accessory respiratory organs enable them to tolerate adverse and muddy environmental conditions. Verma et al. (2008) recorded 2.1 t ha⁻¹ catfish production in makhana-integrated culture, while Pramanik et al. (2013) reported more than 63% benefit from the makhana–fish system through integrated nutrient management (Verma et al., 2008). Makhana is well suited to such systems because it thrives in water-retentive, clayey soils rich in organic matter (Khadatkar et al., 2020).

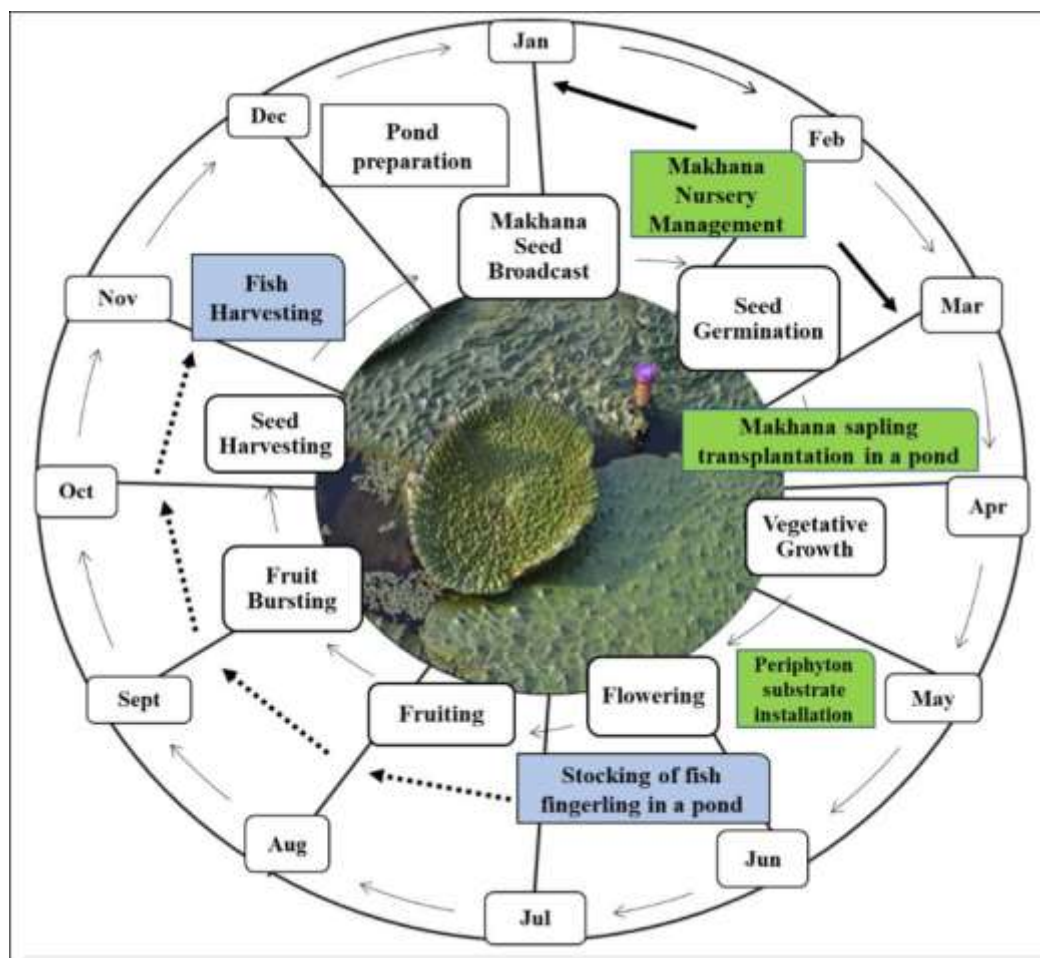


Fig.1: Life cycle stages of makhana plant along with the appropriate timing for fish fingerling stocking and harvesting
(Source: Raut et al., 2025)

VI. FISH SPECIES SUITABLE FOR MAKHANA PONDS

Makhana ponds contain diverse ecological niches, and fish with different feeding habits can be combined to utilize natural food resources such as plankton, detritus and periphyton. Since makhana is the main crop, the selected fish should adapt to its ecological conditions and should not adversely affect crop growth. Important considerations include tolerance to high temperature, low dissolved oxygen, muddy conditions and water-level fluctuations, along with fast growth, hardiness and availability of natural food organisms (Mishra et al., 2003; Sinha, 2018). Air-breathing fishes are particularly suitable because the extensive makhana canopy shades the water surface and can reduce dissolved oxygen (Dana et al., 2018). Suitable species include singhi (*Heteropneustes fossilis*), magur (*Clarias batrachus*), koi/kabai (*Anabas testudineus*), garai/saur (*Channa* spp.) and mud eel

(*Macrognathus* spp.). Other fishes reported for integration include *Chanda* spp. and freshwater prawn (*Macrobrachium* spp.). These species are relatively tolerant of the muddy and oxygen-limited conditions typical of makhana ponds. Indian major carps and exotic carps are generally less suitable under dense makhana coverage because the extensive leaves restrict air-water exchange and reduce dissolved oxygen, making conditions less favourable for conventional carps. However, maintaining sufficient open-water spaces in the centre or along the pond periphery can improve oxygen availability and facilitate the culture of oxygen-dependent species such as rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus mrigala*). Thus, open-water management can allow greater flexibility in fish selection while maintaining both makhana and fish production (Ayyappan and Raman, 2003; Raut et al., 2025).

Species that feed on or damage macro vegetation should be avoided. Where predatory wild air-breathing fishes are present, adequately sized fingerlings should be stocked to minimize predation. Overall, species selection should consider ecological tolerance, feeding niche, compatibility with makhana, growth and survival, seed availability and market demand to achieve sustainable and productive makhana–fish integration (Sinha, 2018).

VII. METHODS OF FISH AND MAKHANA INTEGRATION

The following conceptual model may be experimented and adopted for the integration of makhana-fish culture. Makhana pond may be deliberately stocked with fish as is being done in a fish pond. Even within this system it is necessary to differentiate between simultaneous and alternate production while referring to the harvest of makhana and fish. Hence the integrated cultural system may be further differentiated into: (Mishra et al., 2003)

- (i) Concurrent makhana-cum-fish culture
- (ii) Rotation of makhana-cum-fish culture

(i) Concurrent makhana-cum-fish culture

The fish may be reared concurrently with the growing of makhana. In practicing such type of integration, the following design may be adopted

- (a) Central vacant space
- (b) Peripheral vacant space.

(a) Central vacant space: Here one square or circular vacant space, about 10-15% of the total water spread area in the centre of the pond, should be enclosed by fixing bamboo poles 15cm apart where the sprawling makhana leaves will not be allowed to spread and cover the water surface. The sunlight falling on the entire pond will not penetrate inside the water column owing to the shading effects of the large leaves. In the vacant central space, the solar radiation will fully penetrate inside the waterbody. The primary producers, tiny phytoplankters will accumulate in the middle vacant space of the pond and will photosynthesize liberating oxygen as byproduct. This will to some extent compensate the depletion of oxygen in other parts of the blanketed waterbody. These phytoplankters will be grazed by the herbivore zooplankters and these in turn will be fed upon by the

carnivore zooplankton which will be finally preyed upon by the fishes. Thus, the grazing food chain will fully operate in the vacant space in the middle of the pond where from the plankters will be dispersed in other parts of the pond (Mishra et al., 2003).

(b) Peripheral vacant space: In this case 10-15% of the entire water-spread area in the peripheral portion of the pond should be left vacant by enclosing through the bamboo poles where solar radiation will penetrate up to the bottom. The phytoplankters in this zone will get enough sunlight for photosynthesis. The sprawling makhana leaves will fully cover the large central zone of the pond. The loss of space either in the central part of in the peripheral part of the pond will be compensated by added income from the production of fish (Mishra et al., 2003).

(ii) Rotation of makhana cultivation and fish culture

Rotation permits better care of both makhana and fish. The model depicts that the seeds of makhana sprouting in February and growing rapidly during May – June and even up to July. By then the entire pond is fully covered with Leaves. Fruiting takes place till August and September. Fruits burse and the seeds scatter to the bottom of the pond which are collected by scanning the bottom mud. Stocking the pond with the seeds of Indian major and exotic carps and 1200 (8-10g) air-breathing fish (*Clarias batrachus*) in November and harvest by April could yield about 500kg fish

Pen system:

The pen system is another approach for integrating makhana and fish culture mostly adopted in the *Chaur* wetlands of Bihar (Raut et al., 2024). In this model, a portion of the *Chaur* lands, preferably a marginal or peripheral site, is enclosed using bamboo poles or netting. The enclosed area, or "pen," is specifically reserved for fish rearing while makhana is cultivated in the rest of the water body. This design is particularly suitable for areas where there is a natural division between the shallow and deeper parts of the *Chaur*. The pen system offers several advantages. First, it creates a controlled environment for fish rearing, protecting them from predators while still allowing access to natural food sources like detritus, plankton, and small invertebrates. Second, it prevents fish from damaging makhana plants, which is important since some fish species, particularly herbivorous types, may feed on aquatic vegetation.

The pen also facilitates easier fish management, including stocking, feeding, and harvesting, since the enclosed area can be more easily accessed than the larger, open-water body. This model is particularly effective in *Chaur* lands that have irregular

topography or where complete separation of fish and makhana is not feasible. The pen system allows for better utilization of unused marginal sites (Raut et al., 2024).

SYSTEMS OF INTEGRATED FISH CUM MAKHANA CULTIVATION

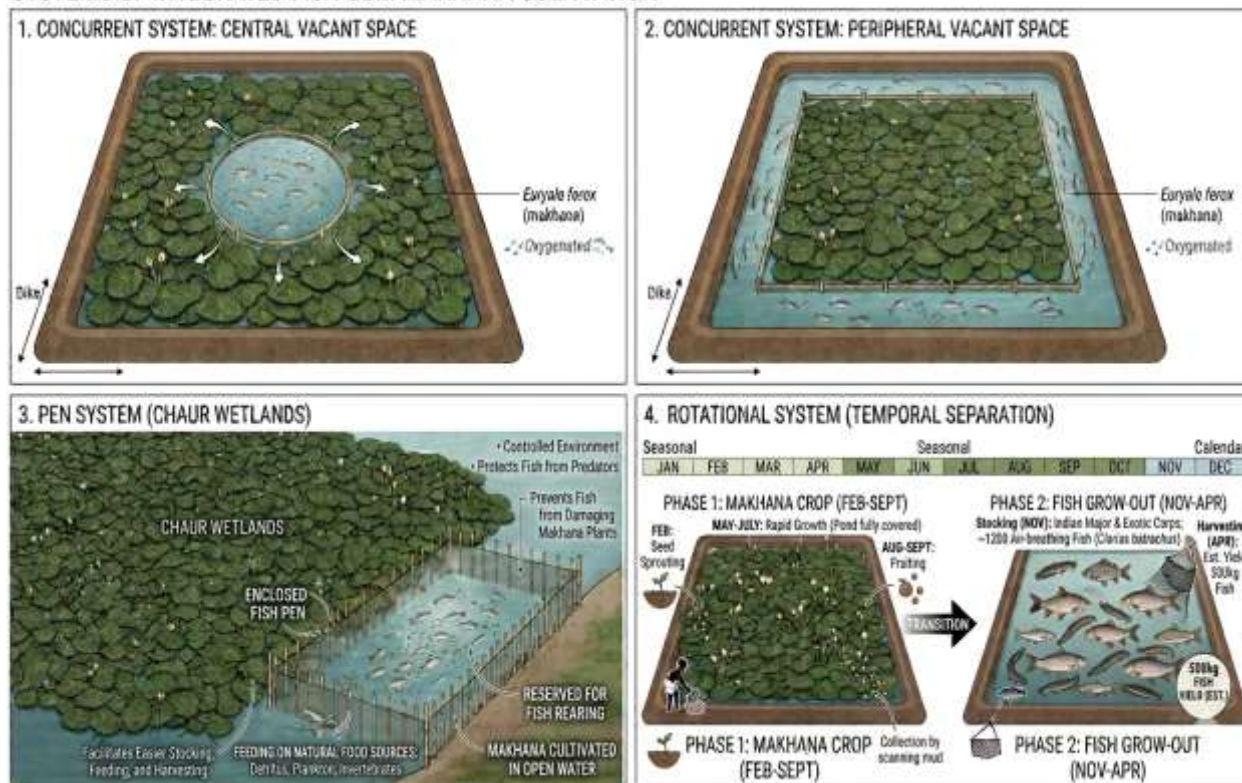


Fig.2: Illustration of different methods of fish and makhana integration systems

VIII. STOCKING AND MANAGEMENT OF FISH

Stocking of Fish Fingerling Stocking of advance fish fry (size 20-30 mm, 2-4 g) in makhana-fish integrated systems coincides with the makhana plant's life cycle, specifically between its vegetative growth (sprawling leaves) and flowering periods. This timing is crucial because the water body's conditions during this phase provide an ideal environment for the stocking of fish. The dense aquatic vegetation from makhana offers shelter for fish, while the water's nutrient balance supports optimal growth. The stocking ratio should be balanced according to their ecological niches. A stocking density of 1 fingerling @ 2 m² is recommended. This density ensures enough space and resources for the fish to grow without overcrowding, which could lead to competition for food and oxygen.

Feed management is critical in the integrated makhana-fish farming system due to the lower primary productivity typically found in makhana ecosystems. Since the aquatic environment under makhana cultivation has less natural production of phytoplankton and other primary food sources, supplemental feeding becomes essential for ensuring the optimal growth of fish from the fingerling stage to marketable size. Locally available materials like rice or wheat bran mixed with mustard oil cake in a ratio provide a cost-effective and nutritious feed base. Adding a small quantity of vitamin and mineral premixes further improves fish health and growth rates. Additionally, pelleted, sinking commercial feed available in the market offers better results and is easy to use. The recommended feeding rate is 2-5% of the fish's body mass, adjusted according to their growth rate. The daily ration should be & divided into two

equal portions and applied in the morning and evening.

Health of fish is directly influenced by the aquatic environment. Therefore, regular monitoring of various parameters is essential for effective management. Critical monitoring includes fish growth, mortality-causing agents, disease occurrence, and water quality. These parameters help ensure the overall health and productivity of the system.

Additionally, the fortnightly of organic manure plays an important role in increasing the abundance of plankton and zooplankton in the ecosystem. Managing of ecological parameters like temperature and organic load, along with regular weeding and timely fish harvesting, farmers can optimize the performance of their makhana fish culture systems, ensuring a healthy, sustainable, and economically viable operation. After completing the lifecycle of makhana (*Euryale ferox*) during the month of Aug-Sep, its fruit bursts open, scattering seeds at the bottom of the pond. The seeds are then collected. Simultaneously, fish harvesting is also conducted after the makhana lifecycle ends, as the water temperature starts to drop and fish growth rates slow down, particularly during the Nov-Dec. This timing is ideal because it allows the fish to grow to marketable size without negatively affecting the makhana crop. The fish are harvested either through netting or draining the pond, depending on the pond's depth and fish species. Hence, both fish and makhana seeds are harvested, the pond is prepared for the next crop season (Raut et al., 2024; Raut et al., 2025).

IX. PRODUCTION AND ECONOMIC ADVANTAGE OF MAKHANA-FISH FARMING

- i. Puste et al. (2004) studied the integration of makhana (*Euryale ferox*) and water chestnut (*Trapa bispinosa*) with fish culture was undertaken during pre- to post-monsoon season at 'Tal' wetlands in the subtropics under new alluvial zone of West Bengal, India. In the integrated systems, the highest cumulative makhana yield equivalence was recorded in the Makhana + Live-fish system (Magur - *Clarias batrachus* & Singi - *Heteropneustes fossilis*) (4.97 t ha⁻¹), followed by Makhana + Rohu (*Labeo rohita*) & Catla (*Catla catla*) (4.43 t ha⁻¹). The
- Makhana + Live-fish system also achieved the highest gross monetary return (Rs. 149,300 ha⁻¹), net profit (Rs. 52,980 ha⁻¹) and benefit-cost ratio (3.71). In comparison, Water chestnut + Live fish and Water chestnut + Rohu & Catla recorded cumulative yield equivalences of 4.82 and 4.68 t ha⁻¹, respectively. Overall, the study demonstrated that integrating makhana with fish can improve the overall production value and profitability of wetland-based farming systems. The higher overall production value and profitability were attributed to the synergistic interaction between fish and aquatic crops, improved resource utilization, control of aquatic weeds and associated insects, and diversification of farm output. The compatibility of live fishes with makhana was also identified as an important factor contributing to the superior performance of the integrated system. Overall, the study demonstrated the potential of makhana-fish integration to enhance the productivity and economic viability of wetland-based farming systems.
- ii. Sodi and Kumar (2019) studied integrated makhana-fish aquaculture under field conditions in Katihar district, Bihar, during 2012-15, comparing the system with sole makhana and carp culture. The integrated system used makhana with carp polyculture comprising Mrigal, Grass carp, Silver carp, Common carp, Rohu and Catla, stocked at 3,000 fingerlings in a ratio of 10:10:20:20:20:20. Approximately 10% of the pond area (50 × 10 m) was maintained as an open-water space to facilitate solar radiation penetration, oxygenation and fish growth. The integrated pond produced 5.26 tons ha⁻¹ of carp fish, 0.23-ton ha⁻¹ of wild fish and 1.55 tons ha⁻¹ of makhana, compared with 4.72 tons ha⁻¹ of carp fish in the control pond. The economic performance favoured the integrated system, with net profits of Rs. 59,739 ha⁻¹ from sole makhana cultivation, Rs. 259,195 ha⁻¹ from sole carp culture in the non-integrated pond and Rs. 329,801 ha⁻¹ from integrated makhana-carp aquaculture. Thus, the integrated system provided both fish and makhana from the same water body while achieving the highest net profit, demonstrating its

potential to improve production, income and livelihood security in rural Bihar.

- iii. Kumar (2025) assessed the economic performance of integrated fish-makhana farming compared with makhana monoculture in the wetlands of Kishanganj, Bihar, based on a survey of 80 farmers. The integrated system involved a total production cost of ₹72,456/ha, compared with ₹39,972/ha for makhana monoculture. However, integrated farming generated ₹227,640/ha gross income and ₹155,184/ha net income, compared with ₹112,140/ha gross income and ₹72,168/ha net income under monoculture. The integrated system also recorded a higher benefit-cost ratio (BCR) of 3.14, compared with 2.80 for makhana monoculture, while the cost-income ratio (CIR) was 0.23 and 0.35, respectively. The integrated system therefore provided higher income and profitability despite its greater production cost, demonstrating the economic advantage of combining fish with makhana cultivation
- iv. Raut et al. (2025) evaluated the performance and economic feasibility of semi-intensive makhana-fish integration at four locations in Bihar, India. The integrated system stocked Catla, Rohu, Mrigal, Bata, Climbing perch and Snakehead at 6,000 fingerlings ha⁻¹ in a 3:2:2:1:1:1 ratio. A peripheral vacant space design was adopted. The system produced 1.55 ± 0.085 t ha⁻¹ makhana seed and 1.48 ± 0.15 t ha⁻¹ fish, compared with 1.78 ± 0.133 t ha⁻¹ makhana seed under sole cultivation. Despite the slightly lower makhana yield, fish production increased the net return to ₹2,74,007.89 ± 83,648 ha⁻¹, compared with ₹1,78,820 ± 18,633.40 ha⁻¹ under sole makhana cultivation. The biomass of Catla and Rohu was higher than the other stocked fish species, and they were compatible with makhana cultivation in an integrated aquaculture system. Water and soil physicochemical parameters also differed between the systems, with integrated ponds showing higher dissolved oxygen, than sole makhana ponds, along with lower TDS and electrical conductivity. Sediment organic carbon, available nitrogen and potassium were also higher in the integrated system. These changes were attributed to fish excreta, supplementary feed and decomposition of makhana biomass,

indicating enhanced nutrient recycling within the integrated pond ecosystem. The integrated system also supported greater phytoplankton and zooplankton diversity. However, dense makhana canopy and decomposing plant residues may reduce dissolved oxygen and adversely affect water quality, highlighting the need for proper canopy and pond management

These results indicate that the major advantage of makhana-fish farming is not necessarily maximizing the yield of makhana alone. Rather, it is the additional production and income obtained from the same water body.

Fish integration in makhana ponds has been reported as a potential biological approach for controlling associated aquatic weeds. In a field comparison from North Bihar, plots integrated with cultured fish showed reduced weed growth compared with non-integrated plots. The integrated plots were stocked with herbivorous and molluscivorous fishes, including common carp, grass carp and black carp, and produced 10–12 quintals acre⁻¹ of makhana compared with 8–10 quintals acre⁻¹ in non-integrated plots. Farm income was approximately ₹50,000 acre⁻¹ in the integrated plots compared with ₹20,000–25,000 acre⁻¹ in non-integrated plots. The observed weed suppression was attributed to fish feeding on aquatic weeds and bottom-dwelling molluscs, indicating that fish integration may provide simultaneous benefits of biological weed control, additional fish production and improved economic returns (Sinha & Jha, 2025). However, controlled studies are required to quantify species-specific weed-control efficiency and determine optimal fish stocking densities in makhana ponds.

X. LIVELIHOOD DIVERSIFICATION THROUGH FISH-MAKHANA INTEGRATION

Makhana is deeply connected with the livelihoods of communities involved in its cultivation, harvesting, processing and marketing. In Bihar, approximately 5 lakh families are reported to participate directly in cultivation, harvesting, popping and marketing activities. Traditional knowledge associated with makhana production has been particularly preserved among the Mallah community of north Bihar, where

specialized knowledge has developed for cultivation, underwater harvesting and processing (ICAR, 2019; Sharma et al., 2025; Warshini et al., 2025). The crop generates employment across the entire value chain, including pond preparation, seedling production, cultivation, harvesting, seed cleaning, drying, roasting, popping, grading, packaging, transportation and marketing. The livelihood significance of makhana can be further strengthened through integration with fish culture. Makhana–fish integration provides an additional source of income, particularly for small and marginal farmers dependent on seasonal or leased water bodies. Makhana provides crop income, while fish provides an additional source of revenue from the same aquatic resource. This diversification reduces dependence on a single commodity and improves the economic productivity of existing water bodies (Singh et al., 2021). The integrated system also creates employment through fish harvesting, handling, processing, marketing and value addition and is particularly relevant in areas where waterlogged land has limited suitability for conventional crops (Singh et al., 2017).

The sector has witnessed substantial expansion in recent years. Between 2020 and 2025, the cultivated area increased by 40–50%, from 25,000–27,000 hectares to 35,000–40,000 hectares, while total production almost tripled, increasing from 40,000–45,000 MT to 1.1–1.2 lakh MT. This growth has been supported by improved agronomic practices, a shift towards field-based cultivation and wider adoption of integrated makhana–fish farming systems, which have enhanced yields and farmer incomes. Makhana has traditionally been cultivated mainly in the eastern and northeastern states of India, particularly Bihar. However, the development of mechanical popping and increasing market demand have encouraged entrepreneurs in other regions, including Madhya Pradesh, Himachal Pradesh, Telangana, Haryana, Chhattisgarh and Uttar Pradesh, to explore makhana cultivation, trading, value addition and marketing. Increasing demand for popped makhana from developed countries further creates opportunities for integrating makhana with suitable fish species, offering potential benefits for Indian farmers and commercial entrepreneurs (APEDA, Monthly dashboard –Makhana (Fox-Nut) Nov-2025).

The benefits of makhana–fish integration, however, depend on equitable distribution of returns throughout the value chain. Improved access to improved varieties, institutional credit, mechanized harvesting and popping, organized marketing and direct market linkages will be important for ensuring that increased production translates into improved farmer livelihoods.

XI. CONSTRAINTS AND FUTURE PROSPECTS

Despite its potential, makhana–fish farming faces several technical and socioeconomic constraints. Traditional makhana cultivation and harvesting remain labour intensive, while underwater seed collection and manual popping involve substantial physical drudgery. Dependence on skilled divers, traditional harvesting tools and limited access to improved harvesting technologies further constrain the sector [7,10]

From the aquaculture perspective, optimum fish stocking density, species combinations and feeding strategies require further standardization. Excessive makhana coverage may reduce dissolved oxygen, whereas excessive fish biomass may increase organic loading. Fish mortality and harvesting challenges, stemming from high plant density and the presence of prickly characteristics, as well as decomposed plant residues. These factors can lead to decreased dissolved oxygen levels in the water. Therefore, future research should focus on optimizing the balance between makhana plant density, fish biomass and water quality (Dana et al., 2018; Raut et al., 2025).

Future development should focus on increasing system-level productivity rather than maximizing either makhana or fish production independently. Integration with compatible fish species, improved water management could further enhance farm profitability (Kumar, 2025).

There is also a need for quantitative nutrient-budget studies to determine the movement of nitrogen and phosphorus among fish, makhana, plankton, microbial communities and sediments. Life-cycle assessment, water-use efficiency, carbon footprint and energy-use studies, digital water-quality monitoring, nutrient-flow modelling are also required to evaluate

the long-term environmental sustainability of integrated production systems.

Most importantly, makhana-fish farming should be evaluated as a circular aquatic production system in which water, nutrients, biological resources and labour are utilized to produce multiple outputs from the same production area. Such an approach can improve resource-use efficiency while simultaneously generating food, employment and income.

XII. CONCLUSION

Makhana-fish farming represents a promising integrated production system for improving the productivity, profitability and sustainability of waterlogged and underutilized aquatic resources. By combining makhana cultivation with compatible fish species, the system enables multiple food and income outputs from the same production area while promoting nutrient recycling and livelihood diversification. Its potential is particularly relevant for small and marginal farmers dependent on aquatic resources. However, labour-intensive operations, limited mechanization, inadequate scientific management and uncertainties regarding fish-crop interactions remain important constraints. Future research should focus on optimizing crop-fish combinations, water and nutrient management, mechanization and environmental sustainability to establish makhana-fish farming as a scientifically optimized and economically viable integrated aquaculture system.

REFERENCES

- [1] Annual Report 2013-14. ICAR Research Complex for Eastern Region Patna Bihar.pp37-38
- [2] APEDA, Monthly dashboard -Makhana (Fox-Nut) Nov 2025. Retrieved from https://apeda.gov.in/sites/default/files/2026-01/MIC_November_Monthly_dashboard_Makhana_311225.pdf
- [3] Ayyappan, S. & Raman, Ram. (2003). Status of Fisheries Development in Bihar: Challenges and Strategy in the 21st Century.
- [4] Dana, S. S., Ghosh, A., & Kumar, R. (2018). Factors influencing adoption of scientific technologies related to Makhana (*Euryale ferox*)-Cum-Fish culture in Bihar. *Indian Journal of Extension Education*, 54(1), 13-17.
- [5] Dehadrai, P. V. 1972. Proceeding of the Second Workshop on All India Coordinated Research Project on Air Breathing Fishes for Culture in Swamps, 20-21 December 1972, Patna, Bihar, India.
- [6] Edwards, P., Pullin, R.S.V., Gartner I.A.: Research and education for the development of integrated crop-livestock-fish farming systems in the tropics. ICIARM Studies and Reviews 16, Manila, Philippines (1988).
- [7] FAO, (1977). China: Recycling of organic wastes in agriculture. FAO Soil Bull., 40 – Rome
- [8] FAO, (2026). *The State of World Fisheries and Aquaculture 2026 – Blue Transformation: turning vision into impact*. Rome.
- [9] Food and Agriculture Organization of the United Nations. (1986). Integrated fish farming in China. FAO Fisheries Technical Paper No. 347.
- [10] Government of Bihar. (2024). Bihar Makhana at a Glance. Patna: Bihar Horticulture Development Society, Directorate of Horticulture, Department of Agriculture, Government of Bihar.
- [11] Halwart, M. and M.V. Gupta (eds.) 2004. Culture of fish in rice fields. FAO and The WorldFish Center, 83p.<https://hdl.handle.net/20.500.12348/2059>.
- [12] ICAR (2019). Mechanizing Makhana Popping – A way to save health of millions and improve livelihood of Makhana growers. Agricultural Engineering Division, Indian Council of Agricultural Research. Accessed from <https://www.icar.org.in/content/mechanising-makhana-popping-way-save-health-millions-and-improve-livelihood-makhana>.
- [13] Jha, S. N., & Prasad, S. (1990). Makhana Processing. *Agricultural Engineering Today*, 14(3,4), 19-22.
- [14] Jha, S. N., & Prasad, S. (1996). Determination of Processing Conditions for Gorgon Nut (*Euryale ferox*). *Journal of Agricultural Engineering Research*, 63(2), 103-112. Retrieved from <https://snjha.in/wp-content/uploads/2023/05/1598256674.pdf>
- [15] Khadatkhar, A., Mehta, C. R., & Gite, L. P. (2020). Makhana (*Euryale ferox Salisb.*): A high-valued aquatic food crop with emphasis on its agronomic management-A review. *Scientia Horticulturae*, 261, 108995.<https://doi.org/10.1016/j.scientia.2019.108995>
- [16] Kumar, Anil; Yadav, Pankaj Kumar; Nath, Paras; Patel, V B & Kumar, Rajesh (2020); Sabour Makhana – 1: A New Variety, *Indian Horticulture*, Vol. 65, No
- [17] Kumar, L., Gupta, V.K., Jha, B.K., Singh, I.S., Bhatt, B.P., Singh, A.K., 2011a. Status of Makhana (*Euryale ferox Salisb.*) Cultivation in India. ICAR-RCER, Patna Technical Bulletin No. R-32/PAT-21.
- [18] Kumar, S., & Bhatt, B. P. (2016). Integrated farming system: A tool for agricultural sustainability and enhancement in livelihood security for small and marginal farmers. In *Agricultural technology application*

- for enhancing productivity (pp. 213–236). Narendra Publishing House.
- [19] M.S. Gill, J.P. Singh, & K.S. Gangwa. (2001). Integrated farming system and agriculture sustainability. *Indian Journal of Agronomy*, 54(2), 128-139. <https://doi.org/10.59797/ija.v54i2.4790>.
- [20] Mahawar, Hitesh. (2016). A Report on Makhana (Foxnut) Production, Processing and Supply Chain. 10.13140/RG.2.2.36485.22240.
- [21] Mishra, R. K., Vidyanath, J. and Dehadrai, P. V. 2003. Makhana. Indian Council of Agricultural Research, New Delhi, India.
- [22] Mishra, R. K., Vidyanath, J. and Dehadrai, P. V. 2003. Makhana. Indian Council of Agricultural Research, New Delhi, India.
- [23] Nash, Colin. (2011). The History of Aquaculture. 10.1002/9780470958971.
- [24] Pillay, T. V. R.: Aquaculture. Principles and Practices. Fishing News Books, London. (1990)
- [25] Pramanik, B. R., Puste, A. M., Jana, K., Banerjee, K., Das, D. K. and Dasgupta, M. 2013. Makhana (*Euryale ferox Salish.*)-cum-fish culture: An integrated management for better yield. *Bangladesh. J. Sci. Ind. Res.*, 48(4): 281-286.
- [26] Rani, P., Upadhyay, D.K., Kumar., A. (2026). Integrated Fish Farming Systems for Sustainable Aquaculture: A Review. *Journal of Fisheries and Zoological Sciences*, 1(2), 36-45. <https://doi.org/10.65385/JFZS0006>
- [27] Rath, R. K. (2000). Textbook of Freshwater Aquaculture. ICAR.
- [28] Raut S.M., Jana, B.R., Kumar, M., Singh, I.S., Sarma, K., Padala, V.K., Ahirwal, S.K., Tarate, S.B., Rout, R.K. and Kumar, A. (2024). Integration of makhana with fish culture in Chaur land for improving farmers' livelihood, Technical bulletin No. 01, ICAR-National Research Centre for Makhana, Darbhanga, Bihar, pp. 27.
- [29] Raut, S., Sarma, K., Singh, I. S., Singh, J., Padala, V. K., Ahirwal, S. K., ... & Bhatt, B. P. (2025). Performance and sustainability of the makhana (*Euryale ferox Salisb.*) cum fish culture system in India. *INDIAN JOURNAL OF FISHERIES*, 72(2), 84-93.
- [30] Shankar, M., Chaudhary, N., Singh, D., 2010. A review on gorgon nut. *Int. J. Pharm. Biol. Arch.* 1 (2), 101–107.
- [31] Singh, D. K., Kumar, A., Kumar, U., & Singh, I. S. (2021). Production and profitability of makhana (*Euryale ferox salish.*) in aquatic ecosystem of North Bihar, India. *Indian Journal of Extension Education*, 57(2), 62-66.
- [32] Singh, I. S., Kumar, L., Bhatt, B. P., Thakur, A. K., Choudhary, A. K., & Kumar, A. (2017). Integrated aquaculture with fox nut-a case study from North Bihar, India. *International Journal of Current Microbiology and Applied Sciences*, 6(10), 4906-4912. <https://doi.org/10.20546/ijcmas.2017.610.461>
- [33] Sinha, C. B. K., & Jha, V. (2025). Impacts of Climate Change on Cultivation of Makhana (*Euryale ferox Salisb.*) and Biocontrol of Associated Weeds-A Case Study of Darbhanga District in Bihar, India. *INTERNATIONAL JOURNAL OF PLANT AND ENVIRONMENT*, 11(02), 388-394. [10.18811/ijpen.v11i02.19](https://doi.org/10.18811/ijpen.v11i02.19)
- [34] Sinha, M. (2018). Integration of makhana cultivation and fish culture: A case study of Darbhanga Division. *International Research Journal of Management Sociology & Humanities*, 9(7), 244–248.
- [35] Sinha, Ranjan Kumar (2023); Supply Chain of Makhana Marketing and Processing in Bihar, Agro-Economic Research Centre for Bihar & Jharkhand, T M Bhagalpur University, Bhagalpur – 812 007 (BIHAR).
- [36] Verma, A. M., Ahmad, S. H. and Jha, V. 1996. Integrated culture of air breathing carnivorous fishes with makhana (*Euryale ferox Salish.*) in a derelict wetland of North Bihar, India. *J. Freshw. Biol.*, 8(2): 117-120
- [37] Verma, A.K., Banerji, B.K., Chakrabarty, D., Datta, S.K., 2010. Studies on makhana (*Euryale ferox Salisb.*). *Curr. Sci.* 99 (6), 795–800.
- [38] Verma, A.M., Jha, V. and Ahmad, S.H., 2008. Fish-makhana (*Euryale salish*) integration: a case study of sustainable aquafarming system in north Bihar. *Journal of the Indian Fisheries Association*, 35, pp.87-96.
- [39] Wardhan, H., Sunthal, T., & Gulati, A. (2025). Strategies to Boost India's Makhana Exports (No. 25-r-13). Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India.
- [40] Warshini, A., Doharey, R. K., Meena, N. R., Verma, A., Yadav, V., & Dixit, A. (2025). Garrett ranking of constraints and satisfaction of Makhana (*Euryale ferox*) growers in Bihar. *Indian Journal of Extension Education*, 61(3), 128-131.