



Integration of Makhana with Fish Culture in *Chaur* Land for Improving Farmers' Livelihood



**ICAR-National Research Centre for Makhana,
Darbhanga- 846 005, Bihar**

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Introduction

India is endowed with a vast expanse of freshwater resources, which can be broadly put under two categories depending on limnological considerations, such as lentic (standing water) and lotic (flowing water) ecosystems. The water spread area of Indian wetlands varies from 4.8 m ha to 7.4 m ha, including the states of Uttar Pradesh, West Bengal, Bihar, and Northeastern states. Among these, the northern region of Bihar is particularly rich in lentic and lotic aquatic resources. In a freshwater ecosystem, rivers are closely linked to wetlands through hydrological connectivity, as riverine systems often feed or recharge wetlands, influencing their water levels, nutrient flow, and biodiversity. Seasonal River flooding can create or sustain wetlands, such as floodplains, oxbow lakes, and marshes, which support diverse ecosystems by providing habitat and breeding grounds for aquatic species.

The river Ganges and its tributaries present tremendous aquatic resources in Bihar. The northern part of Bihar (i.e., the upper part of the Ganges) has many tributary networks of Himalayan-originated riverine systems like Gandak, Koshi, Kamala-Balan, *etc.* Moreover, the riverine tributaries are creating several geographical land structures such as oxbow lakes (i.e., *Maun*), depressed land water bodies (i.e., *Chaur*), spread over 46,000 ha area, and man-made earthen ponds (locally known as *Pokhari*). These riverine systems and their land structures support the enormous aquatic biodiversity in the region. During the seasonal flood, all the water bodies act as shelter, feeding, and breeding grounds for several fish species. The economic activities and employment in north Bihar depend primarily on the agriculture and fisheries sector. The enhancement of the fisheries sector by including fish culture and its trade could be a considerable support to the local people involved in fishery and related activities. In north Bihar, many people, mainly from the fishermen communities, are engaged in traditional aquaculture. They use seasonal and perennial water bodies like *Pokhari* for aquaculture practices and cultivation of aquatic cash crops like makhana (*Euryale ferox* Salisbury) and water chestnut (*Trapa natans*) in *Chaur* and low-lying areas. In addition, there is a vast possibility of rearing fish with aquatic cash crops. It can give surplus income to the concerned stakeholders like fishers, which is an added advantage in sustaining the agribusiness in this part of the country. In this context, we briefly describe the effective utilization of enormous aquatic resources for the rearing of fish with commercial aquatic crops like makhana and the associated potential productivity along with the possible economic benefits to the local fishermen in north Bihar.

Makhana and fish represent economically significant aquatic resources in North Bihar, where their cultivation forms the foundation of local farming communities and ethnicities. The region's unique geography, characterized by various water bodies such as *chaur*, *maun*, and *pokhari* offers an ideal environment for the growth and rearing of these aquatic resources. Furthermore, biodiversity is important for the future sustainability of Inland natural resources, including commercial fisheries and commercial aquatic agronomy. Therefore, from the increasing economic and nutritional importance of aquatic-derived products, the scientific management of the wetland is essential for developing and managing the capture and culture of fisheries along with commercial aquatic crops.

Table 1: Wetlands (<i>Chaur</i> s and <i>Mauns</i>) Resources and Their Characteristics			
Sr. No.	Characters	Floodplain wetlands	Oxbow lakes
1.	Local name	<i>Chaur</i> s	<i>Mauns</i>
2.	Formation	Flood outbreak	River meandering
3.	Geography	Open type- Connected with the river during monsoon season	Close-type meander, a U-shaped Lake or pool that forms when a wide meander of a river
4.	Water holding period	A few months in a year/ Seasonal	Throughout the year/ Perennial
5.	Utilization	Makhana and water chestnut cultivation, capture fisheries	Capture fisheries

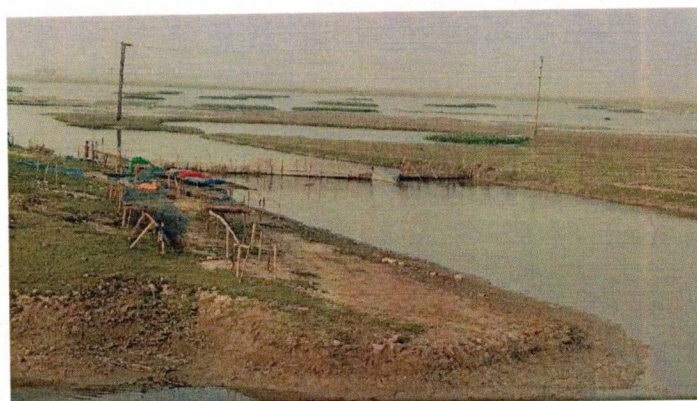


Fig.1: Kusheshwar-Sthan wetland, Darbhanga district, Bihar

Ecological Importance of *Chaur* Land Area

Floodplain wetlands in Bihar are harboring many fish species. The faunistic composition of the floodplain wetland generally reflects that of the parent river. In open wetlands, the catch is dominated by the riverine fauna. The major fish species can be divided broadly into major carp, minor carp, catfishes, snakeheads, feather back, loaches, needlefish, mud eel, spiny eel, and small size prawns. Therefore, those resources are a valuable source of rich and varied endemic stock of many foods, forage, larvicidal, aquarium, and therapeutically important fishes.

The fish fauna generally includes *Puntius* spp., *Trichogaster* spp., *Chanda* spp., *Mystus* spp., *Ambassis* spp., *Amblypharyngodon mola*, *Nandus nandus*, *Macrognathus pancalus*, *M. aral*, *Botia* spp., *Wallago attu*, *Sperata aor*, *Ailia coila*, *Ompok bimaculatus*, *Heteropneustes fossilis*, *Channa* spp., *Anabas testudineus*, prawns, etc., and Indian major carps (*Gibelion catla*, *Labeo rohita*, *Cirrhinus mrigala*). Indian major carps and exotic carps are commonly being used for stocking in commercial aquaculture. Exotic carps such as *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella*, *Cyprinus carpio*, *Oreochromis mossambicus* and *O. niloticus niloticus* are reported from the wetland ecosystem. Many of them are suitable for aquaculture practices in floodplain wetlands ecosystems and as per carrying capacity for

being stocked those fishes under many culture practices like culture-based fisheries, capture-based fisheries, and pen culture by creating co-operative societies, self-help groups, farmer producer organizations, etc., Table 1 shows some of the important indigenous fish species, exotic fishes and prawns from flood plain wetlands and their different values. Presently, the ichthyodiversity of these wetlands is losing its identity due to massive changes in physiographic, hydrological, ecological, and climatic conditions, as well as exploitation patterns.

Table 2: List of Commercially Important fish species

Social values	Species
Food fishes	<i>Catla catla</i> , <i>Labeo rohita</i> , <i>Cirrhinus mrigala</i> , <i>Hypophthalmichthys molitrix</i> , <i>Ctenopharyngodon idella</i> , <i>Cyprinus carpio</i> , <i>Oreochromis mossambicus</i> and <i>O. niloticus niloticus</i> , <i>Bagarius bagarius</i> , <i>Mystus</i> spp., <i>Channa marulius</i> , <i>Clarias batrachus</i> , <i>Clarias magur</i> , <i>Salmostoma</i> spp. <i>Macrobrachium</i> spp.
Ornamental fishes	<i>Puntius</i> spp., <i>Chanda nama</i> , <i>Parambassis</i> spp., <i>Trichogaster</i> spp., <i>Badis badis</i> , <i>Amblypharyngodon mola</i> , <i>Chitala chitala</i> , <i>Devario devario</i> , <i>Esomus danricus</i> , <i>Macrogynathus</i> spp.

Aquatic macrophytes, also known as hydrophytes, are large plants found in water bodies. They may be emergent, submerged or floating, rooted or unrooted in habitat. Aquatic macrophytes thereby play key roles in many functions within aquatic ecosystems as well as generating beneficial ecosystem services directly or indirectly to human society. Macrophytes are harvested from wild stock, or cultivated in flooded areas for food, aquaculture, livestock fodder, and religious significance. In the wetland ecosystem of Bihar, some aquatic plants could be used by fishermen's communities to support livelihood, and those are identified from the wetland ecosystem and commonly found in floodplain wetlands (Table 2).

Table 3: List of Commercially Important Macrophytes in Wetland Ecosystem

Macrophytes	Common name	Use
<i>Azolla pinnata</i>	Azolla	Aquaculture, livestock as a fodder
<i>Trapa natans</i>	Water chestnut	Food and religious
<i>Eurale ferox</i>	Makhana	Food and religious
<i>Acorus calamus</i>	Sweet flag	Food
<i>Nelumbo nucifera</i>	Lotus	Medicine and religious purpose
<i>Bacopa monnieri</i>	Brahmi	Medicine and Ayurved
<i>Eclipta alba</i>	Bhringraj	Medicine and Ayurved
<i>Ipomoea aquatic</i>	Water spinach	Food
<i>Centella asiatic</i>	Mandukaparni	Medicine
<i>Calocasia esculenta</i>	Taro	Food

Phytoplankton plays a crucial role in wetland ecosystems by serving as the primary producers and forming the base of the food web, supporting higher trophic levels like fish and birds. Zooplankton contributes to nutrient cycling, controls algal populations, and maintains ecosystem balance. The phytoplankton community in the *Chaur* land areas is mainly represented by three major classes: Cyanophyceae (blue-green algae), Chlorophyceae (green algae), and Bacillariophyceae (diatoms).

Chlorophyceae: This class dominates the phytoplankton population in the *Chaur* lands, dominated by species such as *Cosmarium* sp., *Oedogonium*, *Spirogyra* sp., and *Closterium* sp. These green algae thrive in nutrient-rich environments, particularly in areas with moderate sunlight and temperature, contributing to high primary productivity.

Bacillariophyceae: Species of diatoms, including *Navicula* sp., *Nitzschia* sp., *Gomphonema* Sp., *Gyrosigma* sp., *Hannaea* sp., and *Synedra* sp. are prevalent. Diatoms are highly sensitive to environmental conditions such as temperature and nutrient availability, showing reduced abundance during the winter due to lower dissolved nutrients and temperature.

Cyanophyceae: species of blue-green algae, including *Nostoc* sp., *Chroococcales* sp., *Spirulina*, and *Oscillatoria*, are observed throughout the year. *Cyanophyceae* species are capable of nitrogen fixation and can tolerate a wide range of environmental conditions, although their population density is less during winter due to reduced nutrient availability. Phytoplankton diversity is influenced by the competition with macrophytes (large aquatic plants), which often dominate these ecosystems. Macrophytes efficiently absorb nutrients from the soil and water, leaving less for phytoplankton growth. In macrophyte-dominated areas, chlorophyceae species tend to prevail, while Bacillariophyceae show dominance in other regions due to their ability to adapt rapidly to nutrient-depleted environments.

Zooplankton: The diversity of zooplankton in *Chaur* lands complements the phytoplankton community, forming a critical link in the aquatic food web by grazing on phytoplankton and serving as prey for fish and other aquatic animals. Common zooplankton groups include rotifers, copepods, and cladocerans, which vary in abundance based on seasonal changes and nutrient availability. The interaction between phytoplankton and zooplankton ensures a balanced ecosystem, regulating primary productivity and nutrient cycling in these lentic ecosystems.

Cultivation of Makhana in *Chaur* Land Area

Makhana, also known as gorgon nut, thrives in the shallow, stagnant waters typical of the *chaurs* and *mauns*. These perennial water bodies, scattered across the floodplains, provide the perfect conditions for makhana cultivation due to their stable water levels and nutrient-rich sediments. Makhana farming is labour-intensive, requiring careful water management and harvesting techniques. However, it is highly profitable, with the seeds being used in food products, traditional medicine, and cosmetics, providing a vital source of income for rural communities.

Similarly, fish farming in these water bodies is a key livelihood activity for many farmers in North Bihar. The availability of perennial water resources makes the region suitable for the rearing of various fish species, including carp and catfish, which are both popular in local diets and have significant market demand. The integrated cultivation of fish alongside crops

like makhana allows for efficient use of water resources, enhancing overall productivity and sustainability.

Additionally, other aquatic cash crops like water chestnut (*Trapa natans*) are cultivated in these water bodies. This adds another layer of economic value for the farmers, diversifying their sources of income. Cultivating makhana along with other aquatic crops, not only supports the livelihoods of the local communities but also contributes to the region's agricultural and economic resilience.



Fig.2: Cultivation of Makhana in the *Chaur* land



Fig.3: Water chestnut is one of the commercial aquatic crops

Makhana nursery management

Effective management of makhana nursery ponds is crucial for a successful cultivation cycle. Makhana, an aquatic crop, thrives in clayey soil rich in organic matter, which provides the necessary nutrients for robust growth. The field preparation begins with 2-3 deep ploughings to ensure proper soil aeration and structure. Organic manure is applied as required, enhancing soil fertility, and promoting healthy seedling development. Once the field is prepared, it is filled with water up to 0.46m, creating an ideal environment for makhana cultivation. Seeds are sown in December, with a recommended 20 kg of healthy seeds broadcasted per hectare to ensure optimal density and growth. A dedicated nursery area of 500 square meter is maintained to cultivate seedlings under controlled conditions. By March, the seedlings are mature and ready for transplanting into the main pond. Aphid management is an integral part of nursery pond management. Regular monitoring and eco-friendly pest control methods help maintain the health of the seedlings, preventing any potential damage from aphids. Integrated pest management practices, such as introducing natural predators or using neem-based sprays, effectively control aphid populations without harming the crop. Overall, meticulous nursery pond management, from soil preparation and seed sowing to pest control, ensures high-quality makhana seedlings. This foundation supports vigorous growth and maximizes yield, contributing to the sustainability and profitability of makhana cultivation.

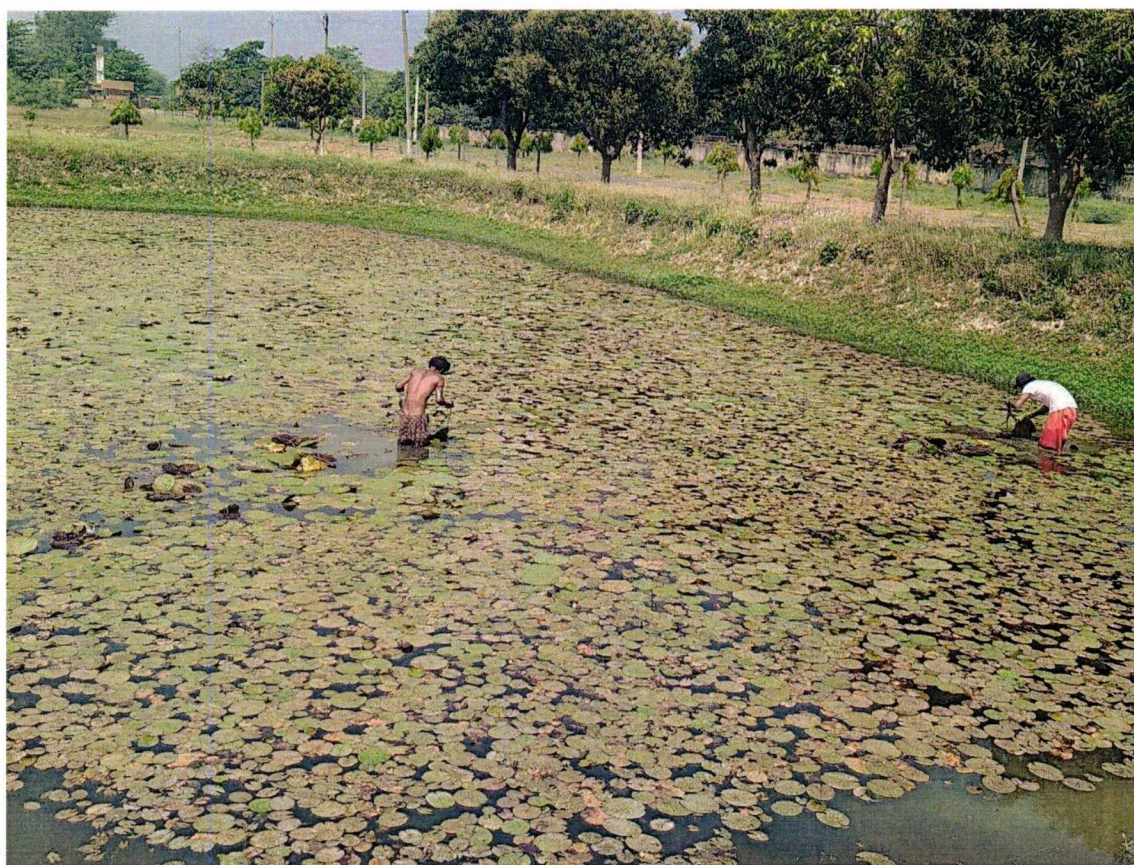


Fig.4: The collection of makhana saplings (a variety of 'Swarna Vaidehi') from the nursery pond is being maintained by ICAR-NRCM Darbhanga.

Site Selection

Several key factors must be considered when selecting a site for integrated aquaculture in *Chaur* land area. These include soil type, pH, availability of high-quality water, access to roads, and electricity. The site should be free from seasonal flooding and pollution. Additionally, the site must have access to a reliable surface or groundwater source for filling the pond or exchanging water as needed. Wetlands that experience seasonal water accumulation are ideal, as they allow pond development at a lower cost. Considering all these factors is crucial for successfully implementing an integrated aquaculture system.

Soil

Soil quality plays a crucial role in determining ponds' productivity and water quality, as well as the suitability for dike construction. Key factors such as soil structure and permeability are assessed to evaluate a site's appropriateness for pond development. The pond bottom must be capable of retaining water effectively. The most suitable soil types for pond construction include loam, clay loam, and silty clay. Ideally, the proportion of gravel should not exceed 10%. Soil types such as rocky, sandy, gravelly, and limestone-based soils are generally unsuitable for fish pond construction and should be avoided. If a dugout pond is to be supplied by surface runoff, the site must have enough impervious soil to prevent excessive seepage losses. The most suitable locations are those with fine-textured clay or silty clay extending well below the planned pond depth. Sites where sandy clay reaches sufficient depths are generally acceptable. However, sites with porous soil or underlain by layers of coarse sand or sand-gravel mixtures should be avoided unless one is prepared to invest in an artificial lining. The performance of nearby runoff-fed ponds with similar soil conditions can serve as a reliable indicator of the suitability of a proposed site. The pond bottom should be made firm and impermeable to prevent leakage. This can be achieved by repeatedly puddling the bottom soil mixed with clay, allowing it to settle for a week, and then repeating the process several times. This should be continued until water seepage is reduced to a minimal level.

Selection of dimensions of the pond

The dimensions of an excavated pond are primarily determined by the required water capacity, with depth being the most critical of the three dimensions (length, width, and depth). All excavated ponds should have a depth that meets or exceeds the minimum necessary for the specific site. The depth must extend sufficiently into the water-bearing material for ponds fed by groundwater to ensure a reliable supply. The maximum depth is generally influenced by the type of material being excavated and the equipment used. The size and type of excavation equipment can also constrain the width of the pond. For instance, when a dragline excavator is used, the length of its boom often limits the maximum width that can be excavated while allowing for proper disposal of excavated material. The required capacity dictates the minimum length of the pond. To prevent sloughing, the side slopes are typically no steeper than the natural angle of repose of the excavated soil, which varies by soil type. The side slopes are usually maintained at a 1:1 ratio or flatter.

Lining the pond

Excessive pond seepage typically occurs due to poor site selection, where the soils in the impoundment area are too permeable to retain water. Such issues often result from inadequate site investigations and can usually be avoided. In some cases, no ideal site may be available, but the need for water is significant enough to justify using a suboptimal location. In these situations, the pond's design must incorporate measures to reduce seepage by implementing sealing methods. To minimize seepage, soil permeability must be reduced to a level where water losses become insignificant or manageable. The appropriate method for reducing seepage depends on the proportion of coarse-grained materials, such as sand and gravel, and fine-grained materials, like clay and silt, present in the soil. Some pond sites can be made relatively impermeable through compaction alone if the material has a broad range of particle sizes (from small gravel or coarse sand to fine sand) and contains at least 10% clay and silt to form a seal. This is the most cost-effective method. Since seepage losses increase with the depth of impounded water, the thickness of the compacted seal should be proportionally adjusted to accommodate the water depth.

Bunds or dikes around the pond

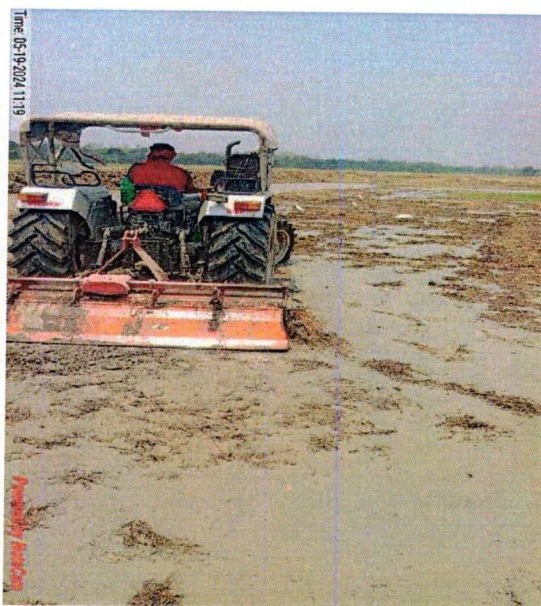
A bund should be constructed around the entire pond, with sufficient width to serve as a pathway for conducting various pond management activities. The height of the bund should extend approximately two feet above the water level, avoiding excessive height or insufficient elevation. The bund should be covered with grass or other suitable vegetation to prevent soil erosion, breakage, and collapse. Dikes should be compact, sturdy, and free from seepage. An ideal dike is constructed with a soil composition of 15%–30% silt, 45%–55% sand, and 30%–35% clay, ensuring optimal strength and impermeability. The slope of the embankment should follow a horizontal-to-vertical ratio of 3:1 for good-quality loamy silt and 2:1 for clay or sandy soils when constructing dikes. This ensures stability and suitability based on soil type.

Preparation of the *Chaur* land area

Preparing *Chaur* land, or lowland areas, is crucial for successful makhana sapling transplantation. First, the land should be ploughed deeply 2-3 times, followed by planking to break up clods and create a smooth surface. Before transplantation, it is essential to retain a sufficient water level in the field, ensuring that the water depth is consistent until the monsoon season arrives. After the initial ploughing, the pond should be puddled by 3-4 runs of a tractor-based puddler to loosen the soil further and remove any aquatic weeds. This process helps in creating a suitable environment for the makhana saplings. After one week, the field should undergo 3-4 more ploughings in the presence of water, to produce a well-prepared puddle. This step is essential for leveling the field, which ensures the uniform distribution of irrigation water, a critical factor for the successful growth of makhana. The depth of ploughing should reach 30-40 cm to promote proper soil aeration. Before the final puddling, a basal dose of organic fertilizer can be applied if needed, to enrich the soil with nutrients, ensuring that the saplings have the optimal conditions for growth after transplantation.



Ploughing



Puddling



Weeding



Bundh making

Fig.5: Development of *Chaur* land area for the rearing of fish with Makhana

Manure and fertilizer

Makhana is often grown traditionally in *Chaur* land, which typically possesses nutrient-rich, organic soils due to the accumulation of decayed organic matter. In these areas, natural soil fertility may be sufficient for makhana cultivation, reducing the need for additional fertilizers. However, when soil quality is nutrient-deficient, applying fertilizers becomes crucial for the healthy growth and high yield of makhana plants. It requires approximately 100:60:40 kg of NPK, and organic fertilizers (Farm yard manure 4t/ha + oil cakes 0.8t) are also essential.

Transplantation of makhana sapling

Transplantation of healthy makhana saplings ensures successful crop growth. Typically, the transplantation takes place in February-March when the vegetative growth conditions are optimal for plant establishment. The selected saplings should be healthy and well-developed, ensuring that they can thrive once transplanted into the prepared field. To promote optimal growth, each makhana sapling should be spaced at an ideal space of 1.5 square meters, which provides enough room for the plants to spread out and access necessary nutrients and sunlight. The plant-to-plant and row-to-row distance should be maintained at 1.25 meters, ensuring that the plants have adequate space to grow without competition for resources. This spacing also facilitates easier management, such as weeding and water control, during the cultivation period. The water depth during transplantation should be maintained at 0.30-0.45m. This water level provides the floating condition for the sapling leaves to establish their roots in the soil while also maintaining an environment conducive to makhana growth. Careful monitoring of water levels after transplantation is essential to prevent stress on the young saplings. By following these practices, farmers can ensure successful transplantation, leading to a healthy makhana crop and maximizing yield.



Fig.6: Transplanted Makhana saplings in *Chaur* area

Flowering and fruiting of Makhana

The flowering and fruiting phase of makhana typically begins between May and June, marking the onset of a vital stage in the crop's development. Makhana plants produce large, showy flowers in shades of purple or pink. A unique feature of this crop is that the flowering

and fruiting occur unsynchronized, meaning flowers and fruits appear at different times across plants. This staggered process results in an extended fruiting season, providing a continuous yield but requiring regular monitoring for efficient harvesting. After pollination, the fruits begin to form, taking approximately six weeks to mature. Upon reaching maturity, the fruits rupture and release seeds into the water. These seeds float for 2-3 days and then eventually settle at the bottom of the water body, where they accumulate. The process of fruit bursting and seed accumulation continues throughout the growing season until harvest time.

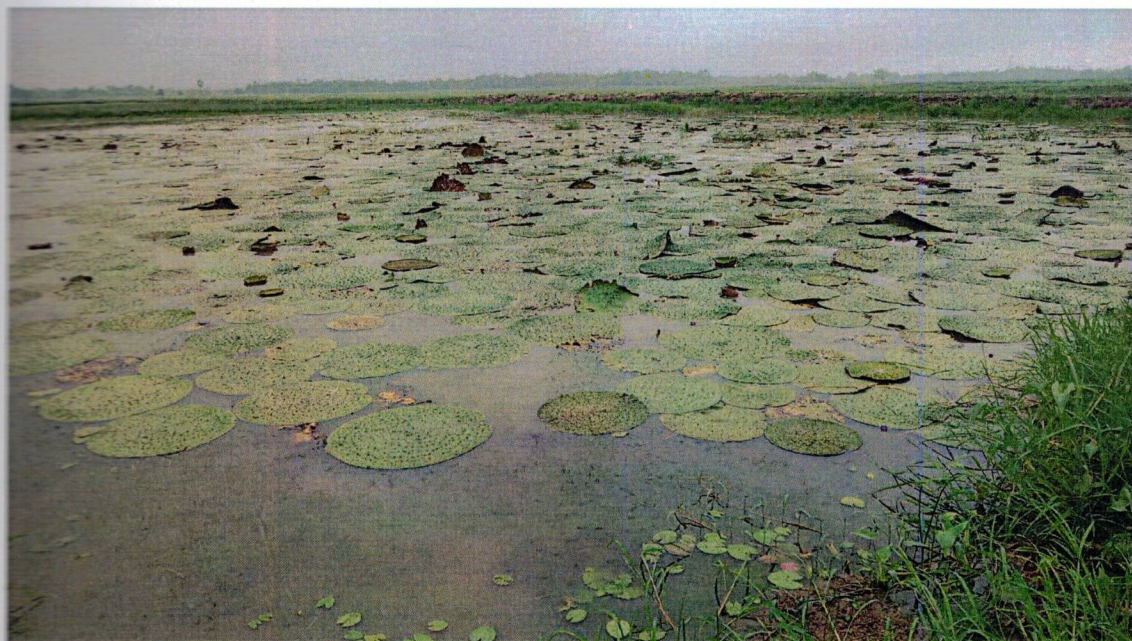


Fig.7: Grown makhana plant (variety, 'Swarna Vaidehi') in *Chaur* land area with flowering and fruiting stage

Models for Makhana cum Fish Culture in *Chaur* Land Area

In an integrated aquaculture system, makhana cultivation is combined with fish farming to optimize the use of water resources and improve productivity. For this integrated aquaculture system, two models can be applied according to their suitability: - *Vacant Space System* and the *Pen System*. These models are designed to provide optimal environments for both makhana growth and fish rearing, balancing the needs of both crops while maintaining ecological sustainability.

Vacant space system

In this model, about 10-20% of the total water spread area in *Chaur* lands (depression areas) is kept free from makhana plants to create a dedicated space for fish rearing. This vacant space is crucial for several reasons. First, it allows better penetration of solar radiation into the water, which is essential for maintaining water quality and supporting the growth of phytoplankton, which serves as a natural food source for fish. The open space also helps to oxygenate the water, compensating for oxygen depletion that often occurs in areas covered by dense makhana leaves, where light penetration is low and organic decomposition is high. The vacant space is enclosed using bamboo (*Bambusa* spp.) poles, nylon threads, or netting to prevent the fish from entering areas densely covered by makhana or spreading makhana leaves into the vacant space. When selecting the site for this vacant space, the bottom topography of the pond or *Chaur* is a key factor to consider. Areas where the water depth is more than one meter are ideal for applying this model, as deeper waters provide better living conditions for the fish, such as maintaining more stable water temperatures and oxygen levels. This model ensures that both fish and makhana can coexist without competition for space and resources. It allows fish to grow in an oxygen-rich environment while makhana thrives in the rest of the pond. Regular monitoring of the water quality and fish health is important in this system to maintain a balance between plant decomposition and oxygen supply.

Pen system

The pen system is another approach for integrating makhana and fish culture. 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.

Both the Vacant space system and Pen system are effective models for integrating makhana and fish farming in *Chaur* lands. The choice between them depends on the specific characteristics of the water body, such as depth, topography, and water quality. Both models, however, focus on optimizing the ecological balance between makhana plants and fish,

ensuring that solar radiation and oxygen levels are maintained for healthy fish growth while maximizing the economic returns from both crops. Proper implementation of these models requires careful planning, regular monitoring, and adaptive management practices to ensure the sustainability of the integrated aquaculture system.



Fig.8: Vacant space system in *Chaur* area for fish rearing with Makhana

Compatible Fish Species with Makhana in *Chaur* Land

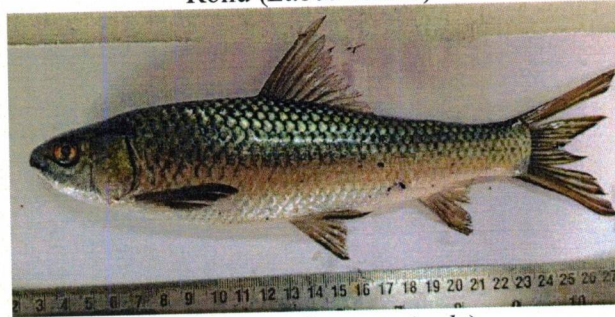
In the aquaculture system of North Bihar, fish farming traditionally follows the polyculture method, which includes Indian Major Carps (IMC) such as Catla (*Catla catla*) rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*), along with exotic carps like silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), and common carp (*Cyprinus carpio*).



Catla (*Catla catla*)



Rohu (*Labeo rohita*)



Mrigal (*Cirrhinus mrigala*)



Channa sp.



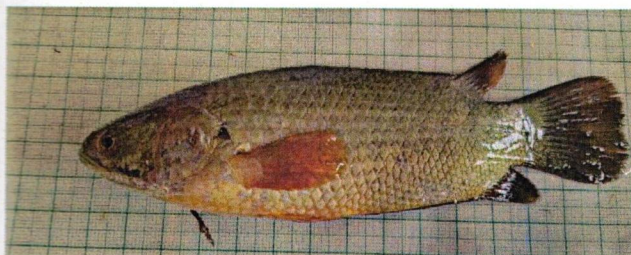
Snakehead (*Channa marulius*)



Magur (*Clarias batrachus*)



Spiny eel (*Macrhnathus spp.*),



Kawai (*Anabas testudineus*)

Fig.9: Commonly found freshwater fishes in *Chaur* land area and those are compactable with makhana

However, in the makhana *cum* fish culture system, the selection of fish species in this system should prioritize fast-growing fish to enhance productivity and reduce cultivation cycles. Using species with diverse feeding habits—such as surface, column, and bottom feeders—ensures efficient use of the water body's ecological niches. Avoiding macrovegetation feeder species is crucial, as they may damage makhana crops.

In addition to traditional carp species, detritivores, and air-breathing fish such as magur (*Clarias batrachus*), singhi (*Heteropneustes fossilis*), spiny eel (*Macroglyphus spp.*), Climbing perch/Kawai (*Anabas testudineus*) and *Channa* species are particularly suitable for cultivation alongside makhana. These species are highly resilient, capable of thriving in the muddy, anoxic conditions typical of makhana ponds. Their high survival rates make them an excellent choice for integrated systems. Lastly, market demand should guide fish selection, ensuring the farming system's economic viability. This thoughtful approach maximizes production efficiency while maintaining sustainability in makhana-fish-integrated farming.

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.

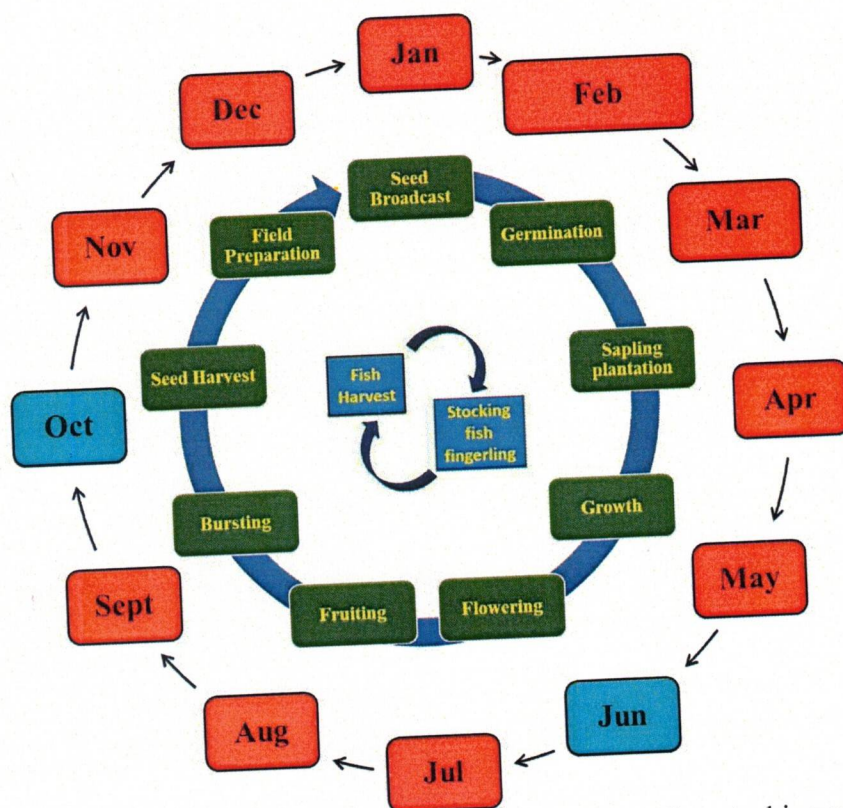


Fig.10: Life cycle of makhana crop and timing for the fish fingerling stocking and harvesting

For effective fish culture, species such as catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), bata carp (*Labeo bata*), climbing perch (*Anabas testudineus*), channa spp., magur (*Clarias magur*) and singhi (*Heteropneustes fossilis*) can be stocked. The stocking ratio should be balanced according to their ecological niches such as catla, rohu, and mrigal primarily feeding on plankton and column feeders, while magur and singhi are detritivores that utilize different food resources. A stocking density of 1 fingerling per 2 square meters 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. Proper stocking management enhances the productivity of both makhana and fish, making the system sustainable and economically beneficial for farmers.

Feed management

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 feed materials like rice or wheat bran mixed with mustard oil cake in a 2:1 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

local 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.

Monitoring of Fish Health

The health of fish is directly influenced by the aquatic environment. Therefore, regular monitoring of various parameters is essential for effective management in an integrated aquaculture system like makhana *cum* fish farming. Critical monitoring includes fish growth rates, mortality-causing agents, disease occurrence, and water quality. These parameters help ensure the overall health and productivity of the system.

In the makhana *cum* fish culture system, water quality often deteriorates due to the decomposition of plant material, particularly makhana leaves. As these leaves break down, they contribute to organic waste buildup, which can affect water quality. To mitigate this, periodic monitoring, and removal of decomposed leaves are necessary, especially in areas designated as vacant spaces system. These vacant spaces, which should occupy about 10-20% of the pond's surface, are important for maintaining water quality and providing oxygenation.

After the makhana seeds are harvested, decomposed organic matter and sediments settle at the pond's bottom. This leads to problems like increased anoxic conditions and higher chemical oxygen demand, both of which are harmful to fish. To address this issue, the chemistry between the water and soil interface should be stabilized. One effective method is using a drag chain to periodically drag the pond bottom, which helps in breaking up settled organic material and prevents it from creating anoxic zones.

Another common issue in the makhana *cum* fish culture system is uneven growth rates among the fish stock. This could be due to competition for resources, health issues, or genetic differences. Screening fish at regular intervals is essential for separating smaller, slow-growing fish from the larger ones. The smaller fish can then be transferred to separate ponds to promote their growth without competition from faster-growing individuals.

One of the most observed diseases in this system is Fin or Tail Rot. This disease is characterized by the appearance of greyish or whitish patches on the frayed fins or tails of fish. To treat this, fish should be dipped in a solution of potassium permanganate (3 mg/L) for a few minutes. If potassium permanganate is unavailable, a common salt solution (5%) can be used as an alternative.

For biosecurity, it is crucial to establish proper barriers to protect the pond from predators and external threats. Installing a peripheral net around the pond and setting up bird fencing are effective measures to prevent the entry of surrounding animals and birds that may harm the fish or contaminate the water. These practices contribute to maintaining a healthy and secure environment for both fish and makhana cultivation. By implementing these monitoring and management practices, the overall efficiency and sustainability of the makhana *cum* fish culture system can be significantly improved.

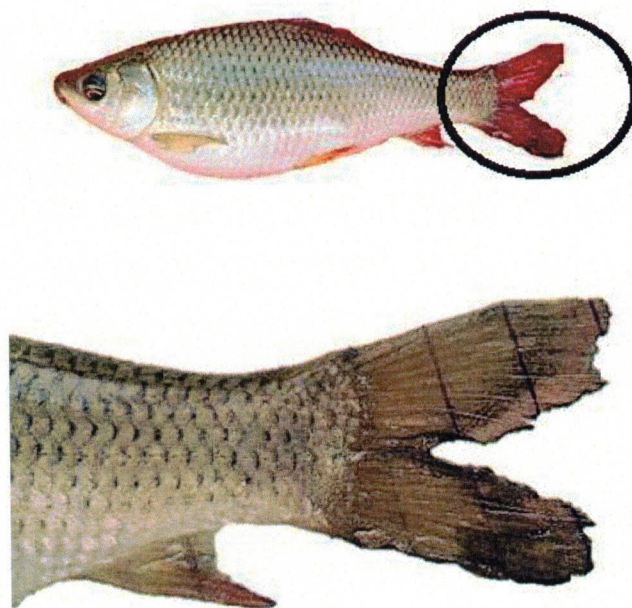


Fig.11: Fin rot on the caudal peduncle of fish

Insect-Pests' Management

Makhana, also known as gorgon nut, is an aquatic plant with edible seeds. However, it is susceptible to various insect pests that can significantly reduce crop yield and quality. Effective insect-pest management strategies are essential for makhana cultivation.

1. Aphid

Order: Hemiptera

Family: Aphididae

Scientific name: *Rhopalosiphum nymphaeae*

It is a significant pest observed during the early/ nursery stage of makhana. The aphid population in the makhana crop started in the last week of December and continues up to the last week of March. The highest aphid population is generally observed in the last week of February. In the makhana crop, a few natural enemies, such as *Coccinellid* predators and parasitoids, suppress the aphid population naturally. Hence, the conservation of natural enemies in the field is essential.

2. Singhara beetle

Order: Coleoptera

Family: Chrysomelidae

Scientific name: *Galerucella birmanica*

This is a major pest of Water chestnut; apart from water chestnut, it also causes considerable damage in makhana. It appears from March – June. grubs and adult-stage beetles are fed on young and mature leaves, causing small holes in the leaves. Grubs are more destructive than adults. To control this pest, synthetic insecticides are used, but these may lead to resistance to

insecticides, resurgence of target pests, residues in food, contamination of groundwater, adverse effects on human health, and mortality of non-target organisms. Biocontrol agents such as *Metarhizium anisopliae* IIVR strain + Neem oil 1%, or *Beauveria bassiana* IIVR strain are effective for controlling of Singhara beetle.

3. Case worm

Order: Lepidoptera

Family: Pyralidae

Scientific name: *Nymphula depunctalis* and *N. crisonalis*

The case worm is a major pest of makhana; it causes heavy damage to crops and reduces the fruit yield considerably. The pests appeared from January to May, and the highest population was observed during March with maximum and minimum temperatures of 30.5°C and 19.7°C, respectively, and the minimum population also appeared in May with maximum and minimum temperatures of 36.7°C and 26.5°C, respectively. For control, spray chlorantraniliprole 18.5 SC @ 0.3 ml per liter of water or Flubendiamide 20% WDG @0.4 ml per liter of water or Lambda-cyhalothrin 2.5%EC @ 1.5 ml per liter of water.

4. Root borer

Order: Lepidoptera

Family: Chrysomelidae

Scientific name: *Donacia delesserti*

This pest is present from April to July on makhana. Stage grubs feed on the root and stem of the plant. Leaves turn yellow initially. Later, the whole plant will die. Adults feed on flowers causes considerable yield loss. For control, apply Carbofuran3G @ 10 kg per acre or spray Chlorantraniliprole 18.5 SC@0.3 ml per liter of water.

5. Leaf midge/ Rib Borer, *Chironomus* sp.

The leaf midge or rib borer population is observed from December to August. The highest population is found from March to July. A minimum population can be observed during August. The larvae of Chironomids are found on developed ribs under the leaf surface. The larvae easily move inside the aerenchymatous cavities of the ribs of the leaves and cause rapid destruction. The color of affected leaves changes to yellow, decays fast, and affects the crop yields.

Besides the above major insect pests, some of the other insects also present as minor pests. These insect pests could gain momentum with the intensification of the makhana crop and may cause significant economic losses to the crop in the future. For management, spray chlorantraniliprole 18.5 SC @ 0.3 ml per litre of water or Flubendiamide 20% WDG @0.4 ml per litre of water or Lambda cyhalothrin 2.5%EC @ 1.5 ml per litre of water.

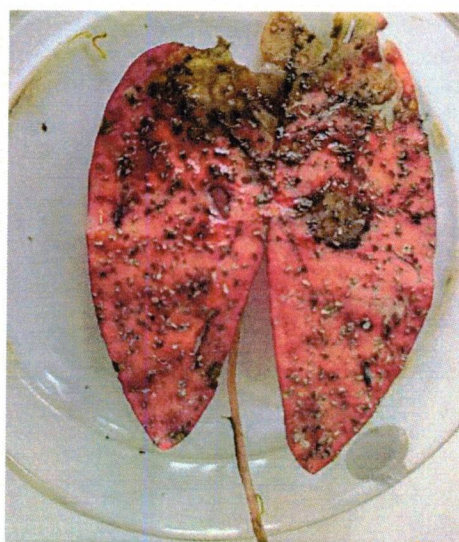


Fig.12: Aphid and Root borer-infected plants from the nursery pond

Seasonal Management Practices

Effective management practices in an integrated makhana *cum* fish culture system require careful attention to ecological parameters across different seasons, such as summer, monsoon, and winter. Each season brings its own challenges and opportunities for both makhana and fish cultivation, particularly regarding water temperature and organic load.

During the monsoon season, water temperatures range between 20-25°C. This period is characterized by a high organic load in the pond, primarily due to the decomposition of

makhana leaves and other aquatic vegetation. The high organic content promotes the growth of unwanted weeds, including submerged plants like *Hydrilla spp.*, floating plants such as *Nymphoides cristatum* Roxb. and *Marsilea minuta* Linn., and filamentous algae. These weeds can interfere with water quality and the overall health of the ecosystem. To prevent these issues, it is necessary to remove the aquatic weeds regularly, either manually or using weeding tools. This process typically requires 4-6 rounds of weeding during the cultivation period to ensure that the weeds do not impact the fish or makhana growth.

Water temperature plays a crucial role in fish growth and health. The temperature peaks during the summer months, especially from March to May, and gradually decreases afterward. By October, water temperatures can drop below 10°C, which significantly impacts the physiological activities of fish, such as metabolism and feeding rates. Lower temperatures slow down the fish's growth, making it difficult to reach marketable sizes. Therefore, it is advisable to harvest the fish before October when the water temperature starts to decline. Doing so ensures that the fish are harvested at their optimal size and growth potential, maintaining the overall productivity of the system. The primary productivity of *Chaur* land is significantly reduced due to the dominance of macrophytes covering the surface area. Hence, effective management of the available open spaces is essential. Additionally, the fortnightly application of organic manure plays an important role in increasing the abundance of plankton and zooplankton in the *Chaur* land ecosystem.

By managing ecological parameters like temperature and organic load, along with regular weeding and timely fish harvesting, farmers can optimize the performance of their makhana *cum* fish culture systems, ensuring a healthy, sustainable, and economically viable operation year-round.



Fig.13: Removal of unwanted weed from the Makhana cultivated *Chaur* land

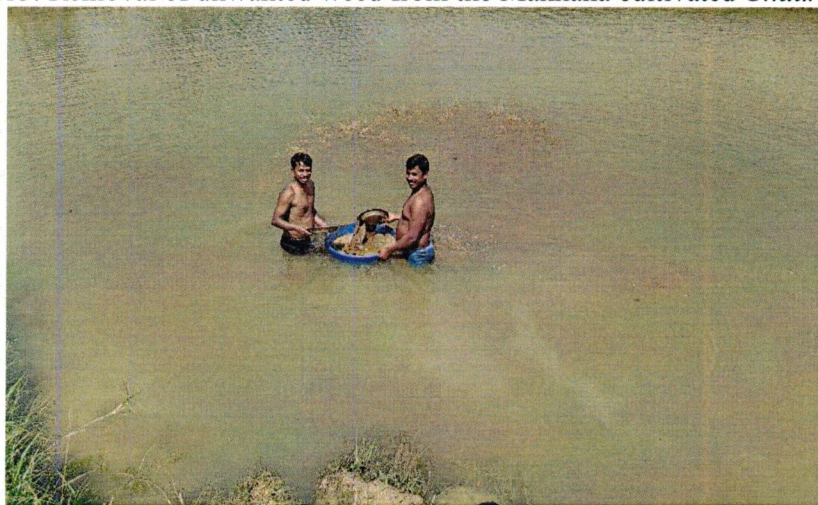


Fig.14: Manuring *Chaur* land area

Harvesting of Fish and Makhana Seed

After completing the lifecycle of makhana (*Euryale ferox*) during the month of July-August, its fruit bursts open, scattering seeds at the bottom of the pond. The seeds are then collected manually using a locally crafted bamboo tool known as a *Ganja*. This traditional harvesting method is labour-intensive but effective in gathering makhana seeds from the pond bed.



Fig.15: Traditional fisher community using *Ganja* for makhana seed removal

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 post-monsoon season. 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.

Once both fish and makhana seeds are harvested, the pond is prepared for the next crop season. This involves cleaning the *chaur* area, drying, eradicating unwanted fish, aquatic weeds, and algae, fertilization, and manuring. Such pre-management practices are essential for maintaining the water quality and ecological balance necessary for successful makhana and fish cultivation in the following season. This cycle of harvesting and pond management ensures the sustainability and economic viability of the integrated farming system.



Fig.16: Harvesting of makhana seed from the *Chaur* land area

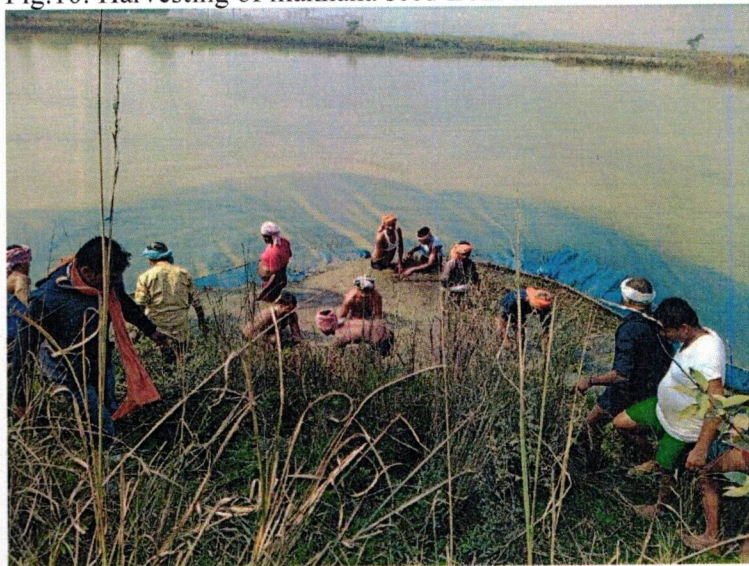


Fig.17: Harvesting of fish from the *Chaur* land area

Advances in the Mechanization of Makhana Seed Harvesting

The most challenging part of makhana cultivation is its harvesting. Since the Mallah community earns a livelihood from both makhana and fish, they cultivate makhana in ponds, lakes, and lowland areas having an average water depth of 10 ft or more. The difficult part is collecting the seeds from the bottom of the pond, requiring multiple dives during seed collection. To address this issue, ICAR-CIPHET has been developing a mechanized system for collecting raw makhana seeds from the ponds. The setup includes a pipe sliding mechanism with a suction inlet and slurry pump. The collection system is equipped with a 5 mm slotted screen for the collection of seeds with water from the dredge.

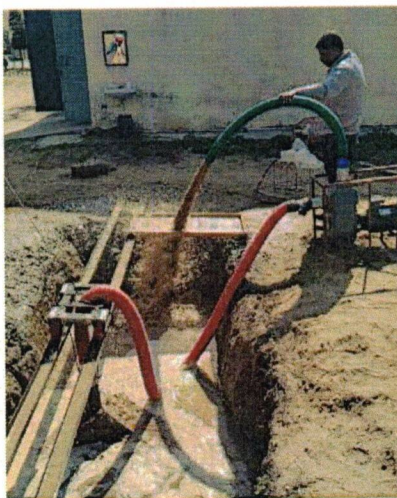


Fig.18: Mechanized system for collecting raw Makhana seeds

However, it has some limiting factors, like buoyancy, float stability, controlling the depth of the collector, direction of water flow, user sitting arrangement, etc. Improvisation is being incorporated to address these limitations.

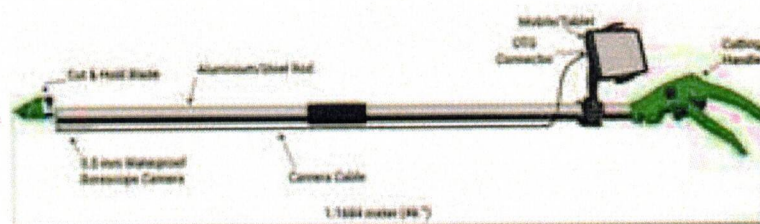


Fig.19: Optical sensor-based Makhana harvester

In the northeastern states, people prefer tender Makhana seeds over roasted and popped ones. So, they harvest Makhana fruits at a premature stage, remove the seeds, and use them in curries, pickles, etc. But the constraint here is that the fruit is spiky and challenging to harvest manually. To address this issue, CAU Imphal, under AICRP on PHET has developed an optical sensor-based Makhana harvester. It consists of a monitor, borescope/point camera, and a cutting blade, applicable for field conditions where water depth goes around 1.5-2 ft. The camera takes images of the fruits underwater and displays them on the monitor, which

helps the operator with site selection and cutting of the fruits. This reduces drudgery during harvesting. It has a capacity of 50-60 fruits/h and costs around Rs. 12,000/-. The field capacity of the equipment is almost double that of the conventional harvesting method.

Economic Analysis

Integrating fish culture with makhana cultivation in *Chaur* lands of North Bihar offers a significant opportunity to boost farmers' income by 50-60%. This increase is primarily due to the synergetic relationship between makhana and fish, which optimizes land and water use with minimal supportive management practices. Makhana, a highly nutritious aquatic plant, grows in shallow water, making it ideal for cultivation in *Chaur* land. Fish, on the other hand, thrive in the same aquatic environment, creating a mutually beneficial ecosystem.

The estimated production from 1-1.5 ha of *Chaur* land can yield 1.5 t of Makhana seeds and 1-1.5 t of fish per cultivation cycle. The presence of fish in makhana fields contributes to natural nutrient cycling, enhancing the overall water quality and providing essential nutrients that promote makhana growth. Species like catla (*Catla catla*), rohu (*Labeo rohita*), and other minor carp are well-suited for these aquatic systems. Moreover, Species like magur (*Clarias batrachus*), and singhi (*Heteropneustes fossilis*) are well-suited for these aquatic systems, as they are air-breathing and thrive in low-oxygen environments, and the production of more than 1.6 tones has been recorded in previous study.

Minimal management practices, such as maintaining water levels and quality, fish stocking density and its ratio, makhana variety, and farming practices, ensure the sustainability of this integrated system. The additional fish yield offers a steady income alongside the makhana harvest, diversifying revenue streams and reducing economic risks for farmers. This eco-friendly approach enhances productivity, promotes sustainable aquaculture, and provides an economically viable solution for *Chaur* land utilization.

Table 4: Economics of Makhana and Fish Production (1.0 ha *Chaur* land)

Sr. No.	Particulars	Makhana production in <i>Chaur</i> land	Makhana and fish production in <i>Chaur</i> land
		Makhana cultivation	Integrated aquaculture
A.	Fish Fingerling	---	6000 fingerlings = 12000 Rs.
B.	Makhana seed	20 kg = 3600 Rs. (180 Rs./kg)	20 kg = 3600 Rs. (180 Rs./kg)
C.	Feed cost	---	Rice bran (1200 kg) = 24,000 Rs. (@ 20 Rs./kg)
		---	Wheat bran (1200 kg) = 42,000 Rs. (35 Rs./kg)
		---	Mustard oil cake (1200 kg) = 36,000 Rs. (@ 30 Rs./kg)
D.	Fertilizer utilized	Cow dung cake (1800 kg) = 1800 Rs. (@ 1Rs./kg)	Cow dung cake (1800 kg) = 9,000 Rs. (@ 5 Rs./kg)
		Farmyard manure (600 kg) = 1200 Rs. (@ 2Rs./kg)	Farmyard manure (FYM) (600 kg) = 3000 Rs. (@ 5 Rs./kg)
		---	Lime (450 kg) = 6,750 Rs. (@

			15 Rs./kg)
E.	Total harvested biomass (Makhana seed/fish)	---	Catla (600 kg) = 1,50,000 Rs. (@250 Rs./kg)
		---	Rohu (680 kg) = 1,70,000 Rs. (@250 Rs./kg)
		---	Mrigal (100 kg) = 20,000 Rs. (@200 Rs./kg)
		---	Bata (120 kg) = 24,600 Rs. (@200 Rs./kg)
		Makhana seed (1700 kg) = 3,06,000 Rs. (@180 Rs./kg)	Makhana seed (1500 kg) = 2,70,000 Rs. (@180 Rs./kg)
F.	Miscellaneous	7,200 Rs.	20,500 Rs.
G.	Labour	35,000 Rs.	70,000 Rs.
H.	Gross expenditure (A+B+C+D+F+G)	48,800 Rs.	2,26,850 Rs.
I.	Gross income (E)	3,06,000 Rs.	6,34,600 Rs.
J.	Net income (E-H)	2,57,200 Rs.	4,07,750 Rs.

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