RESEARCH ARTICLE

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

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Abstract

Climate change across continents is having its impacts in various ways. Agriculture also is being affected in its ways. A crop like Makhana (*Euryale ferox* Salisb.) that is being cultivated in the stagnant water bodies of about 10 districts of Mithila area in north Bihar is also suffering from the problem of diminished supply of water. Smaller rivers are drying up and ponds are also facing the same predicament. Farmers are adapting to this new situation and are cultivating Makhana in otherwise arable plots with only 1.5 to 2 feet of water. Method of transplantation is being practiced. In a way it helps to skip the attack of some initial pests on the crop. But another problem emerges in the form of springing up of unwanted weeds like species of *Pontederia, Jussiaea, Marsilea, Eichhornia, Scirpus* etc. Farmers are making their innovations by integrating fish aquaculture with that of *E. ferox*. The combination of fish types adopted by the farmers also helps in the control of weeds infesting Makhana ponds.

The paper takes into account the present state of affairs faced by Makhana farmers in Darbhanga district and the ways that they choose to tackle the situation as a sequel to climate resilience.

Highlights

- Reduced rainfall in North Bihar has dried up small water bodies, severely affecting Makhana cultivation in the Mithila region.
- Farmers have adapted by shifting Makhana cultivation to shallow, arable plots and using transplantation methods.
- Lower water levels have led to an increase in invasive weeds such as *Pontederia*, *Jussiaea*, *Eichhornia*, *Scirpus*, etc., that obstruct Makhana growth.
- Integrating fish (e.g., Common carp, Grass carp, Black carp i.e; herbivorous and mollusk-eating fishes) farming with Makhana cultivation helps biocontrol of weeds through natural predation.
- This integrated system boosts both Makhana and fish yields while improving nutrient recycling in ponds.
- The study showcases local, resource-efficient innovations that promote climate resilience and sustainable farming.

Keywords: Makhana, *Euryale ferox*, Climate resilience, Darbhanga, Bihar.

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Introduction

Proper resource utilization is getting added attention all over the globe. This is because of meeting the challenges of hunger and protein energy malnutrition. A developing country like India could ill afford to ignore its vast mass of natural resources that need to be harnessed in a proper way. People are generally unaware of the nutritional and medicinal properties of quite a good number of aquatic plants and animals growing in fresh water pools of a state like Bihar.

Bihar is striving hard to emerge as a significant center of second green revolution in India. “More crop per drop of water” is the motto of this national endeavor. Crops with lesser water requirement are being preferred. This is more so in view of the imminent danger of deficient rainfall. An aquatic crop like *E. ferox* that was earlier cultivated in 4 to 5 ft water is now being grown in 1.5 to 2 ft water, as was being practiced earlier in the Kosi division that has a higher water table. The practice of bamboo boring has been very much prevalent in the area. Fish farmers in Darbhanga and Madhubani districts are now fast adopting the practice of growing Makhana in knee-deep water by adopting the practice of transplantation. The process helps the crop skip the attack of early pests (Kumar and Jha 2022). Bihar has a high potential of raising fish production, more so by adopting the recent methods of pisciculture (Sinha 1986, Ahmad *et al.,* 1990. Das 1992, Verma 1995 a, b, Jha *et al.,* 2013 etc.). Fish production in the state has more than doubled in recent years. A recent study made by Raut et al., (2024) refers to the impact of periphyton on makhana cum fish culture. A periphyton based makhana cum fish farming system holds potential to enhance productivity and could be a sustainable farming technique.

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Makhana has emerged as a superfood during Covid-19 period on account of its immunoboosting properties (Jha and Sinha 2024**).** A recent study made by Shaw et al (2024) has experimentally substantiated the Ayurvedic reference on presence of spermatogenic property in makhana. Makhana-based integrated aquaculture has attracted a wider scientific attention (Jha *et al.,* 1991 a, Verma 2005, Jha *et al.,* 2006, Verma *et al.,* 2008, Pramanik *et al.,* 2013 etc.). Integrated Makhana-based aquaculture is facilitated by the association of a number of insects and other animal associations, often acting as pests with the *E. ferox* plants. (Banerji 1972., Mishra *et al.,* 1989, 1990, 1991, 1992, 2003).

Makhana system is ideally suited for integrated aquaculture with air-breathing fishes. Progressive farmers, however, are now integrating culturable carp fishes as well with the system. This is being done by selecting suitable fish species that could feed upon the unwanted weeds that find their way into the Makhana system. A prudent integration could yield its dividends by adopting a suitable choice of fishes. Makhana is known for its good quality protein and starch and is almost fatless (Jha *et al.,* 1991b). As such it is in high demand from affluent countries with high obese population. The novelty of the present communication lies in biocontrol of weeds by the fish species, both inherent and introduced. It further deals with rise in makhana productivity due to biocontrol of associated weeds.

Study Area and Methodology

Present observations were made in the low-lying arable plots of village Belwara under Jale CD block in Darbhanga district of Bihar (Maps 1 and 2). The village is situated alongside the right embankment of the river Khiroi which witnessed a complete cessation of its flowing stream for about a month on account of diminished rainfall in the summer of the year 2024. As such farmers undertook the cultivation of Makhana in about 2 feet deep water.

Figure 1. shows the nearby Khiroi river, fully devoid of water for about one full month during May-June 2024. A 40 years old farmer was of the view that he had not faced a scenario like this in his lifetime. A number of other small rivers in this area also witnessed a similar predicament. Figure 2, however, shows the same river having some water during middle of the August after the rains ensued. Such an unprecedented situation led the farmers adopt a practice of growing Makhana in a low-lying plot that was supplied with irrigation water. Had the rains been normal, Makhana plants would have been planted earlier.

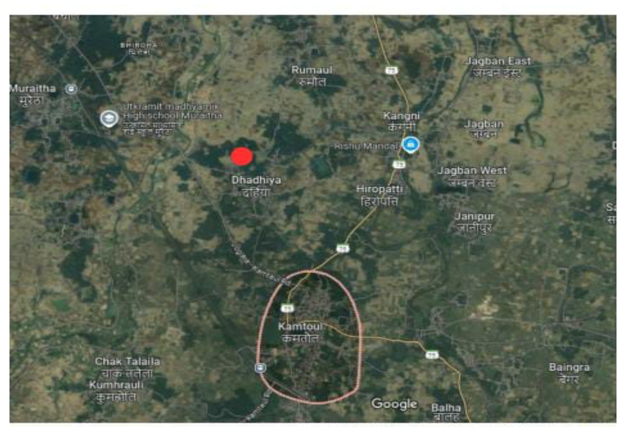
The below two maps (Map.1 and Map.2) show the geographical location and satellite mapping of study sites respectively. The site of present observation (Figs. 3 to 8, Lat.26.333812^0, Long. 85.817049^0) shows an extensive infestation of macrophytic weeds like *Pontederia, Echinochloa, Scirpus* (Kesaur) in the Makhana plot. No such extensive infestation of these weeds was possible if *E.ferox* plants had been planted on time. Results have been presented in the form of 2 maps, 3 tables and 18 figures.

Results and Discussion

Present observations depict the steps taken up by progressive farmers hailing from the village Belwara near Kamtaul in Darbhanga district. This exercise of Khet me Kheti (cultivation of Makhana in arable plot) points to the grim situation that has developed in recent years on account of diminished rainfall. Makhana system is also an ideal system of integrated aquaculture with air breathing fishes as natural occupants at the pond bottom (Raut *et al.,* 2024). Since nothing except seed is taken out of the system, all other parts of the plants are destroyed and they disintegrate in the pond itself. As such a good detritus promotes the growth of fish species like *Heteropneustes fossilis, Clarias batrachus, Anabas testudineus* etc. There is a practice of making heaps of submerged weeds at several points in the waterbody itself. They are not taken out of the water body. This helps retain the nutrient level of the waterbody as the accumulated weeds disintegrate in their own way over course of time. This applies to the floating and emergent weeds that are accumulated on the margin of the waterbody where they disintegrate and their nutrients are replenished back into the system.

A steep rise in the ambient temperature led to the nearby Khiroi river (Fig. 1) completely drying up for about a month during May-June 2024. Farmers had no option other than taking the recourse of irrigating the plot by taking out underground water and maintaining its required level for makhana cultivation. A low water level leads to unwanted growth of weeds on an extensive scale. For this a measure of biocontrol through the

Map 1: Geographical location of Study site
Source: From Brand Bihar.com



Map 2: Satellite mapping of Study site
Source: From Google map

Fig. 1: The river Khiroi at a distance of 250 m from the observation plot having fully dried up for about a month during May-June 2024. (photograph taken on 26 June 2024)

Fig. 2: The same river, almost half filled, after the annual rains have ensued late (photograph taken on 18 August 2024)

Fig. 3: *Jussiaea* sp. as weed in the Makhana water body under observation. (Inset shows the airy roots)

Fig. 4: A severe weed, locally called as Kharsami (*Echinochloa* sp.) in the Makhana pond

Fig.5: *Scirpus* sp. locally called as Kesaur, forms an association with *Pontederia* sp. and prevents the spread of Makhana plants.

Fig. 6: Dense growth of *Pontederia* sp. encircling the Makhana plants.

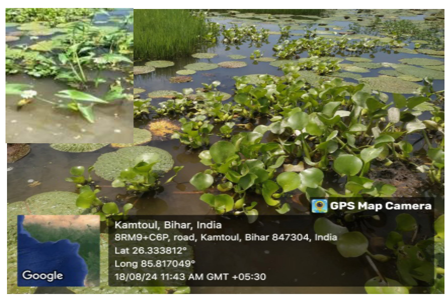


Fig . 7: Multiple no. of weeds, including *Eichhornia crassipes,* outspacing the growth of *E. ferox* plants.

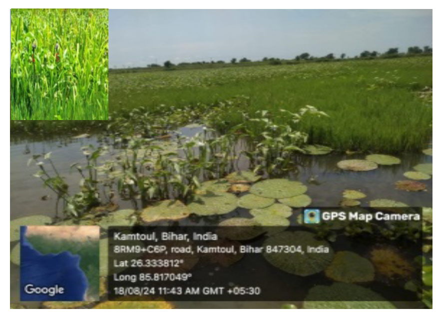


Fig. 8: Multiple no. of weeds at another spot in the same water body. The inset shows a close-up of *Scirpus* sp. and *Pontederia* sp. in close association.

introduction of herbivorous fishes becomes imperative. This helps achieve an enhanced productivity of both makhana crop as well as the associated fish**.**

Excessive growth of algae in Makhana pond also creates a hindrance to the growth of the crop. Recently interventions in the form of adding chemical fertilizers has been made in order to gain enhanced crop field. The increasing use of fertilizers in the crop adds to the nutrient load that also supports the weeds including the algae. Saha *et al.,* (2023) have studied the impact of different treatments and temperatures on algae under Makhana system. Of late, Makhana has attracted a wider scientific attention because of its growing demand at global level. Recent investigations on improved agrotechniques for Makhana production include integrated aquaculture **(**Kumari *et al.,* 2024).

Macrophytic weeds like *Jussiaea, Echinochloa, Pontederia* etc. were found in the area under observation. Of these, *Pontederia* sp. did have an obnoxious growth. A combined onslaught of *Pontederia* sp. and *Scirpus* sp. created a hindrance for Makhana plants that were not allowed to achieve full expansion. *Echinochloa* sp. is otherwise held as a minor millet and there is a need to lay emphasis on its proper utilization

Table 1: List of weeds in order of intensity of infestation

S.No.	*Name*	*Local Name*	*Nature*
1	*Pontederia* sp.	Lauka	Floating
2	*Echinochloa* sp.	Kharsami	Emergent
3	*Jussaiaea* sp.	Banlunga	Floating
4	*Eichhornia* sp.	Kechuli	Floating
5	*Ceratophyllum* sp.	Chaurar	Submerged
6	*Marsilea* sp.	Water Barseem	Floating
7	*Trapa* sp.	Sighara	Floating
8	*Azolla* sp.	Ojola	Floating
9	*Ipomoea aquatica*	Karmi	Floating
10	*Scirpus* sp.	Kesaur	Floating
11	Algal mat	Kai	Floating

(Sayani and Chatterjee 2017). *Trapa* sp. which acts as a weed during the full maturity of Makhana crop is allowed to grow as a rotational crop after the harvest of *E. ferox* seed. While *E. crassipes* belonging to the family Pontederiaceae has a much wider infestation in the entire Mithila region, its allied genus *Pontederia* (syn. *Monochoria*) is more confined to the area under present investigation. *E. crassipes* is otherwise used as a means of capturing fishery in this area (Jha *et al.,* 2012).

Tabe-1 shows the list of different types of associated weeds growing in Makhana waterbody. Fig. 3. shows an extensive growth of *Jussiaea* sp. encircling *E. ferox* leaves that are struggling for expansion. Fig. 4. shows the vigorous growth of *Echinochloa* sp., locally called as kharsami, that prevents expansion of *E. ferox* leaves. Fig. 5. shows the dense growth of *Scirpus* sp. in association with *Pontederia* sp. Both species combine together to create an obstacle to the growth of *E. ferox* on that side. Fig. 5. also shows an excessive growth of rooted macrophyte, locally called lauka, that outpaces the growth of Makhana plants. Such a situation has arisen because there were no rains during early months of Makhana cropping i.e; March onwards. This created an inconducive situation for the crop and this triggered the unwanted growth of weeds like *Pontederia, Jussiaea, Marsilea* etc. Fig. 6. shows an invigorated expansion of *Pontederia* sp. that has encircled the *E ferox* plants. Figs. 7 and 8 show multiple weeds in the Makhana plot including *E. crassipes, Scirpus* sp. and *Pontederia* sp., all in close association with suppressing the expansion of the crop.

Figs. 9 ,10 & 11 show stunted growth of Makhana plants due to excessive onslaught of the submerged weed like *Ceratophyllum* sp. The heaps of submergd weeds accumulated in the pond itself. Photograph in the inset of Fig. 11 shows heaps of aquatic weeds in a Makhana pond elsewhere around this time that are not removed and undergo natural disintegration and add to the nutrient cycle of the crop. This also shows the newly transplanted plantlets (Ntp) of *E.ferox*. Fig. 12. shows *Trapa* sp. growing as weed in the waterbody under observation. It was planted in the previous year as crop. After the harvest of Makhana seeds the left over *Trapa* plants shall be growing as rotational crop. Fig. 13. shows the extensive growth of the local aquatic fern *Marsilea* sp. called water barseem in the plot. It is noteworthy that *Marsilea* sp. turns into an entangled mat in the subsurface area and thus creates a hindrance to the expansion of *E.ferox* leaves. *Marsilea* leaves otherwise do not occupy much space on the upper water surface but underwater extension of its leaf stalks creates the real problem. Fig. 14. shows the minute floating weed called *Azolla* that is otherwise a N_2 - fixing fern adding to the fertility of the system.

One more site lying at a distance of approx 300 meters alongside the right embankment (Figs-15, 18) shows the practice of integrated fish aquaculture in two Makhana plots. Figs. 15 and 17 show the plot in which no fish has been introduced and as such it shows the growth of weeds. At the same time Figs.- 16 and 18 do not show any weed as such. This is because of the introduction of culture fishes like Common carp, Grass carp, Black carp, Naini, Rohu, Silver carp, Bighead carp. It has been showed in Table-2. Since these fishes are basically herbivorous, they feed upon the weeds. Open space in the middle of the waterbody (Fig-16) facilitates the culture fishes that thrive easily on account of dissolution of atmospheric oxygen.

However, in recent years, innovative farmers have taken up a new venture of leaving sufficient open spaces either in the middle or at the peripheral position of the water body. This helps the sustenance of culture fishes like Rohu, Katla, Mrigal as well that thrive on the oxygen dissolved in the water body having open spaces. This helps the growth of both categories of fishes. In recent years innovative farmers have taken up the initiative of introducing Black carp in Makhana ponds. They collect its seeds from the local traders who import it from the neighboring state of West Bengal. Black carp does not feed upon Makhana plants, instead it feeds upon the small mollusks that are available in plenty at the bottom of the water system. So far as the current

Table 2: Integrated aquaculture in Makhana water bodies

Natural Association		*Introduced Fish types*	
Local Name	Scientific name	Local name	Scientific name
Singhi	*Heteropneustes fossilis*	Common carp	*Cyprinus carpio*
Mangur	*Clarias batrachus*	Grass carp	*Ctenopharyngodon idella*
Kabai	*Anabas testudineus*	Black carp	*Mylopharyngodon piceus*
Gainchi	*Macrognathus aculeatus*	Naini	*Cirrhinus mrigala*
-	-	Rohu	*Labeo rohita*
-	-	Silver carp	*Hypophthalmichthys molitrix*
-	-	Bighead carp	*Hypophthalmichthys nobilis*

year 2024 is concerned only very less rains ensued till August. The area achieved very less amount of rainfall.

In recent years, invasive Black carp has also been introduced in Makhana water bodies. It is imported from the nearby West Bengal state, although its transportation from one state to another is illegal. Local farmers introduce this fish in Makhana water bodies to obtain enhanced yield. Black carp feeds upon the small mollusks that grow lavishly in Makhana ponds (Mishra *et al*, 1991, 2003). Mollusks shells are harvested along with raw seeds of Makhana in the month of Sep-Oct. In the present case

Table 3: Comparative yield of raw Makhana seeds and fish in integrated and non-integrated Makhana plots

Input	*Non-integrated plot*	*Integrated plot*
Raw Makhana seeds used for cultivation	12 kg/acre	12 kg/acre
Fish seed introduced	-	3000 fingerlings having an avg. weight of 15-20 g each
Output		
Yield of raw Makhana seeds after harvest (Fingerlings)	8-10 quintals/acre	10-12 quintals/acre
Fish weight after 6 months	1-1.5 kg each	1.5-2.0 kg each
Total income (from sale of fish)	Rs. 20,000-25000/acre	Rs. 50,000/acre

Fig. 9: Stunted growth of *E. ferox* plants at a site where there is a dense growth of submerged weeds(S). Also shows the growth of floating *Ipomoea aquatica* (Karmi saag).

Fig. 10: Dense growth of submerged weeds stunting the growth of the main Makhana crop.

Fig. 11: Farmer showing the extracted submerged weed that competes with *E.ferox* plants for nutrients.

Fig. 12: *Trapa* sp. growing as weed in the Makhana water body under observation

Fig.13: Makhana plot showing excessive growth of *Marsilea* sp.(M)

Fig.14: Floating weed of *Azolla* sp. (A) in the water body under observation.

Fig. 15: An adjacent plot alongside the right Khiroi embankment showing dense growth of Makhana plants that are to be thinned out for transplantation elsewhere (photograph taken on 20th May 2024)

Fig. 16: Another adjacent plot alongside the right Khiroi embankment in which space has been left in the middle for the introduction of culture fishes. (photograph taken on 20th May 2024)

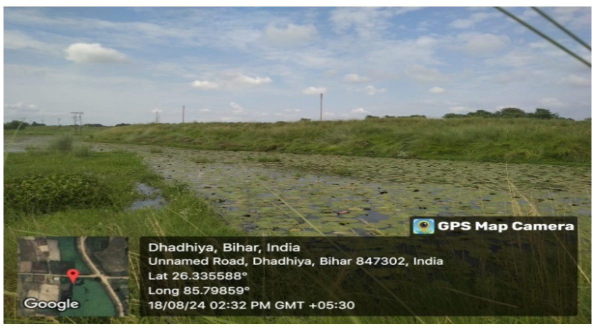


Fig.17: The same Makhana plot (as in Fig. 15) alongside the right Khiroi embankment showing the development of weeds as no fishes have been introduced in this plot. (photograph taken on 18th August 2024).

Fig.18: The same Makhana plot (as in Fig.16) showing no infestation of weeds as fishes have been introduced in this water body. (Photograph taken on 18th August 2024).

Black carp was introduced in Makhana water body in June and in one year it achieved a growth of 3-4 kg. Its market price is generally double the price of other fish species sold in the area.

Table 3 provides an account of the input and output of raw Makhana seeds and fish in non-integrated and integrated plots. 12 kg of raw Makhana seeds for cultivation were used per acre in both the plots. The non-integrated plots yielded 8 to 10 quintals/acre of Makhana seeds as against 10 to 12 quintals/acre in the integrated plot.

The non-integrated plot did have only a natural association of indigenous, detritivorous and air-breathing fishes that achieved an average weight of 1 to 1.5 kg each. As against this, 3,000 fingerlings per acre of culture fishes, having an average weight of 15 to 20 gram each, were introduced in the integrated plot. Within 6 months this plot yielded fish output in the range of 1.5 to 2 kg each by weight. So far as income from this exercise is concerned, the non- integrated plot yielded an income of Rs. 20,000 to Rs.25,000 per acre. The integrated plot, however, yielded an income of Rs. 50,000 per acre. The present findings are indicative of the biocontrol of associated weeds by adopting non-chemical method. This also helps minimize the further unwanted growth of weeds due to preventable nutrient input in the form of agricultural chemicals.

Conclusion

There is a need to raise the production and productivity of the wonder crop called Makhana. This is because of its increasing demand in national and international markets. All efforts are being made to bring more and more of waterlogged areas in Bihar and other states under Makhana cropping by incorporating the practices leading to adaptation as a sequel to climate change. This system also helps incorporate integrated aquaculture practices that could further boost meeting the challenges of the blue revolution in the country.

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