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Stocking Hatchery-Produced Mola (*Amblypharyngodon mola*) Seed in Carp Polyculture Ponds: A Performance Assessment in Odisha, India

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Abstract

Small indigenous fish species (SIS) such as mola (*Amblypharyngodon mola*) regarded as natural 'superfoods,' due to their high nutrient content, offer a promising avenue for addressing the nutritional deficiencies in India. Over the past decade, integrating mola into conventional carp polyculture systems has emerged as a promising nutrition-sensitive innovation, significantly enhancing micronutrient intake, particularly for women and children. However, the lack of hatchery-reared mola seed has hindered the sustainability of this approach. Recently, this bottleneck was addressed by developing a hatchery-based mass seed production protocol for mola, which was introduced into carp farming systems on a pilot basis. This study evaluates the performance of hatchery-produced mola seed in homestead carp polyculture ponds in Odisha, India by using a field survey. Of the surveyed farmers, 24% purchased mola spawn, while 76% opted for mola fry. The average pond size of surveyed farmers was 0.32 ha with an average culture duration of 9 months. Farmers stocked mola spawn at an average density of 283,583/ha and fry at 22,190/ha. Results showed that 93% of farmers achieved successful mola production, with an average mola yield of 194 kg/ha and total production of 2831 kg/ha. Mola contributed an average of 9% to the total fish production reaching a maximum contribution of up to 26%. The mola fish contributed significantly to the household in terms of additional revenue. Household consumption averaged 14 kg of mola per year, with a per capita consumption of 3 kg. Increasing pond size and optimizing stocking density emerge as critical factors positively impacting mola production and income. Overall, this study demonstrates the potential of hatchery-produced mola seed in promoting nutrition-sensitive aquaculture in Odisha, offering valuable insights for its scaling up.

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Introduction

Undernutrition poses a formidable developmental challenge for India, demanding urgent attention. Recent data from the National Family Health Survey underscores the gravity of childhood malnutrition, revealing that 36% of Indian children are stunted, and 32% are underweight (IIPS-ICF, 2021). Micronutrient deficiencies, particularly in vitamins A and D, iron, iodine, and zinc, are pervasive in the region. Addressing this issue requires effective food-based interventions that improve dietary quality, encourage diverse nutrient-rich food consumption, and boost overall energy and macronutrient intake.

Small indigenous fish species (SIS) from freshwater ecosystems play a crucial role in the diets of many fish-dependent populations in South Asia. Recognized as natural 'superfoods,' SIS are prized for their abundant protein, fatty acids, vitamins, and minerals. SIS also present nutritional advantages as they are often consumed in their entirety, encompassing the head, bones, and eyes, thereby utilizing all the available nutrients, including micronutrients. Over the past decade, the integration of SIS into conventional carp polyculture was promoted as a promising innovation that could significantly enhance the intake of micronutrients among farming households. The focus of this promotion has been on introducing mola (*Amblypharyngodon mola*), a species that contains higher levels of micronutrients compared to commonly farmed fish such as carps and tilapia. Mola is a valuable source of essential nutrients, including calcium, iron, vitamin A, and vitamin B12. 100 g of the edible portion of mola contains 2503 μg of Vitamin A (Bogard et al. 2015). Additionally, mola is rich in essential amino acids, omega-3 PUFAs, and lipids, while having a protein content comparable to most carps (Bogard et al., 2015; Mustafa et al., 2015).

WorldFish has played a pivotal role in promoting nutrition-sensitive carp-mola polyculture across South Asian countries, yielding significant quantities of mola without compromising carp yields (Roos, Islam, & Thilsted, 2003; Wahab, Alim, & Milstein, 2003; Roos, Wahab, Hossain, & Thilsted, 2007; Milstein, Wahab, Kadir, Sagor, & Islam, 2009; Ali, Jahan, Belton, Dhar, & Rashid, 2016). Subsequent research has demonstrated that incorporating mola into carp polyculture systems can increase the consumption of micronutrient-rich mola by women and children (Karim et al., 2016; Castine et al., 2017). Moreover, this approach has proven to be cost-effective in addressing the problem of micronutrient malnutrition (Fiedler, Lividini, Drummond, & Thilsted, 2016).

In Bangladesh, carp-mola polyculture has seen widespread success, and similar promising outcomes have been reported in India. Over the past decade, its adoption has gained momentum in states such as Assam, Andhra Pradesh, Bihar, and Odisha. This expansion has been driven by government initiatives and internationally funded programs, with active involvement from small-scale farmers, women's self-help groups (WSHGs), cooperatives, farmers' institutions, and civil society organizations (Dubey et al., 2024a, Dubey et al., 2024b).

Reports from various carp-mola polyculture systems in Asia highlight diverse levels of mola productivity, primarily influenced by stocking densities. In small-scale homestead ponds, settings, average mola production typically ranges from 150 to 300 kg/ha (Dubey et al., 2024c). Depending on the stocking density for carps (2500–16,000/ha) in the carp–mola polyculture system, annual carp production ranges from 0.7 to 3.7 t/ha (Dubey et al., 2024c). Carp–mola polyculture is considered a holistic approach to developing sustainable aquaculture technology. It enhances the average productivity of high-value carp species for commercial purposes while also providing highly nutritious small fish for household consumption. This integrated approach improves the overall nutritional quality of the total production.

Unlike most modern aquaculture practices that rely on hatchery-produced fish seed, the introduction of mola has traditionally involved sourcing broodstock from natural environments. For aquaculture to be commercially viable, it is crucial to produce high-quality fish seed in sufficient quantities at an affordable cost. While hatchery-based seed production technologies are well established for species like carp, catfish, and tilapia in South Asia, the development of similar techniques for SIS has largely been overlooked. This gap poses a challenge to the sustainable scaling of carp-mola polyculture due to the lack of reliable methods for mass mola seed production.

Recently, this challenge was addressed with the successful development of hatchery-based protocols for induced breeding and mass seed production of mola at a private hatchery in Tulunga village, Tirtol block, Jagatsinghpur district, Odisha (Gogoi et al., 2023; Rajts et al., 2023). This hatchery has since begun distributing mola seed to carp farmers including WSHGs, facilitating the scaling of carp-mola polyculture. Data was systematically collected from these mola seed buyers at procurement, followed by a comprehensive survey in 2023 by using a structured questionnaire, covering various aspects such as pond characteristics, seed information, production, income, and consumption.

This paper aims to assess the performance of hatchery-produced mola seed in carp polyculture ponds. Since hatchery-based mola seed production is a relatively new technology, no prior studies have evaluated its production performance in carp polyculture systems. Specifically, we seek to answer the following research questions: What are the productivity trends and income generated from carp-mola polyculture with hatchery-reared mola seed? What are the fish consumption rates among farming households that have adopted carp-mola polyculture? What factors influence the productivity and household consumption of mola?

The findings of this study will serve as a baseline for future research in promoting nutrition-sensitive aquaculture in fish-dependent states across India. Additionally, the insights gained will be instrumental in scaling up mola farming as a strategy to combat undernutrition, highlighting the importance of integrating nutrient-dense SIS into existing aquaculture systems.

Materials and Methods

The hatchery located in Jagatsinghpur district, Odisha either sold or distributed mola spawn and fry to carp farmers at regular intervals. From July 2022 to December 2022, 30 farmers took mola seeds from the hatchery. Basic details of seed buyer farmers were recorded and performed a follow-up survey to understand the production potential of hatchery-produced mola seed in homestead carp polyculture ponds.

The study systematically captures fundamental information about mola seed buyer farmers on the day of procurement. The seeds were intended for stocking in household ponds and Gram Panchayat (GP) tanks across Jagatshingpur, Kendrapara, and Cuttack districts, encompassing 6 blocks and 21 villages. This initiative took place between July and December 2022. The majority of mola seed buyers were male (93%). The average age of these farmers was 46 years, ranging from 30 to 62. All participating farmers underwent farm-gate training, specifically focusing on seed stocking and adhering to culture guidelines. Additionally, they received training manuals in the local language.

A follow-up survey was conducted in 2023, targeting farmers who had completed or were nearing the end of a one-year production cycle. To ensure comprehensive data collection, a structured questionnaire was devised and administered, incorporating both open- and close-ended explorative questions where applicable for gathering of both qualitative and quantitative data. The data collection format encompassed the following comprehensive information: (i) pond size and characteristics (ii) quantity of mola seed purchased and corresponding prices (iii) harvesting details of mola and other fish (iv) mola sale and associated income and (v) household consumption of mola.

Based on "in-depth interview" with a "recall method", we gathered information of a total of 29 farmers in the follow-up survey process. Throughout the entire survey of the respondents, stringent ethical considerations were upheld, ensuring adherence to ethical standards. Informed consent was diligently obtained from the survey participants before the initiation of data collection.

To examine the factors influencing the productivity and household consumption of mola, Spearman's rank correlation analysis was employed. The primary objective was to observe the relationships between a set of explanatory variables, including the age of farmers, household size, pond size, stock density, etc. Additionally, outcome variables such as the quantity of mola and other fish harvested and sold, household consumption, total production, and income were considered.

In this analysis, the null hypothesis posits that as the ranks of one variable increase, the ranks of the other variable are not more likely to increase or decrease. In such a scenario, the Spearman correlation coefficient, denoted as ρ ("rho"), is expected to be 0. If the dependent variable tends to increase as the explanatory variable increases, the Spearman correlation coefficient is positive. Conversely, if the dependent variable tends to decrease as the independent variable increases, the Spearman correlation coefficient is negative. A Spearman correlation of zero signifies no tendency for the dependent variable to either increase or decrease with changes in the independent variable. When the independent and dependent variables are perfectly and monotonically associated, the Spearman correlation coefficient (rho) reaches its maximum value of 1.

In mathematical notation, the Spearman correlation coefficient is written as:

$$\rho = 1 - [(6\sum d_i^2)/n(n^2-1)] \quad (1)$$

Where d_i = difference in paired ranks and n = number of cases.

Results & Discussion

Among the surveyed farmers, 24% purchased mola spawn, and 76% opted for mola fry (1–1.5 inches in size) for stocking. A significant 79% of the ponds were dried before stocking. The hatchery sold a total of 1.23 million mola seeds, generating a sales revenue of 40,250 INR (Table 1). Mola spawn, on average, was priced at 1176 INR per 1 lakh, while mola fry were sold at an average price of 300 INR per thousand.

Mola seeds are transported in a 10-liter polythene bag, filled one-third with water. The empty space above the water is then filled with compressed pure oxygen from a cylinder. The bag is sealed tightly using a jute string or rubber band to prevent the escape of water and oxygen. For protection during long-distance transport and optimal space utilization, oxygen-packed seed bags are placed inside sturdy cardboard boxes or strong plastic bags to prevent damage and heating during transportation. Plastic bags were doubled with an inner bag of 0.05 mm thickness, and an outer bag of 0.4 mm thickness.

Fry were starved and conditioned for two hours prior to transportation. The density varies based on travel conditions such as temperature, distance, and duration of transportation. The packing density was 500 to 1000 mola fry and 25,000 to 50,000 spawn per seed bag. Motorbikes are the preferred transportation method for 80% of farmers. Upon arrival at the pond site, mola seeds were acclimatized gradually by adding water from the receiving pond. This adjustment helps to equalize temperature and other water quality parameters before releasing the seeds.

The average size of homestead ponds was 0.32 ± 0.31 ha (ranging from 0.04 to 1.29 ha), in contrast to the GP tanks with an average size of 1 ha. Notably, over 50% of the pond size ranged from 0.1 to 0.5 ha. The average distance of the ponds from the hatchery was 18.86 ± 29.70 km (ranging from 2 to 160 km), with approximately 48% of the ponds located within a 10-kilometer radius.

Farmers stocked mola spawn at an average density of 2,83,583 numbers/ha, with the majority (29%) opting for a stocking density of 200,001 to 350,000 nos./ha for mola spawn (Table 2 and Fig. 1). Mola fry were stocked at an average density of 22,190 numbers/ha, with 55% of farmers choosing a density within 10,000 nos./ha (Table 2 and Fig. 2). The average culture duration was 9 months, with 52% of farmers following a cultivation period of 10-11 months.

Table 1. Information on mola seed sale and unit price.

Seed types	Farmers purchased (nos.)	Quantity (nos.)	Unit price (INR)	Total amount sold (INR)
Spawn	7	11,30,000	1176.19/ lakh	13800.00
Fry	23	93,500	300.72/ thousand	26450.00
Total	30	1223500	-	40250.00

Table 2. Details of mola seed stocking density.

Seed Type	Stocking Density (nos./ha)	Pond size (ha)
Spawn	2,83,583 ± 90462 (1,23,553 – 4,11,842)	0.57 ± 0.13 (0.40 - 0.80)
Fry	22,190 ± 22266 (1544 – 76,032)	0.31 ± 0.31 (0.04 - 1.29)

Note: Data is expressed as Mean ± Standard Deviation (SD). Figures within the parentheses indicate the range.

Table 3. Total mola and other fish production and income through hatchery-produced mola seed.

Parameters (n = 29)	Unit/ ha	Unit/ household
Mola harvested and sold (kg)	123 ± 49 (30.89 - 222.39)	48 ± 43 (5 -170)
Mola consumed and gifted (kg)	52 ± 32 (10 - 124)	14 ± 12 (4 - 40)
Total mola produced (kg)	194 ± 81 (62 - 445)	69 ± 56 (10 - 210)
Carps and other fish produced (kg)	2637 ± 1153 (412 - 4695)	1034 ± 1141 (70 - 5000)
Total fish production (kg)	2831 ± 1168 (555.99 - 4867.97)	1104 ± 1175 (84 - 5090)
Total income from mola sale (INR)	19681 ± 11546 (2100 - 59305)	7354 ± 6614 (700 - 27000)
Contribution of mola in total production (%)	8.68 ± 6.13 (1.77 - 25.93)	8.68 ± 6.13 (1.77 - 25.93)

Note: Data is expressed as Mean ± Standard Deviation (SD). Figures within the parentheses indicate the range.

Mola production commenced within 3-5 months of seed stocking, with 93% of farmers achieving successful mola production through hatchery-produced seed. Harvesting practices varied, with 31% of farmers opting for partial harvesting and the remaining 69% performing complete harvesting, primarily utilizing cast nets and drag nets. The majority of farmers directed the produced mola for household consumption and additional income through sales.

Mola production averaged 194 kg/ha, with 34% of farmers obtaining 151-200 kg/ha and 28% achieving 101-150 kg/ha (Table 3 and Fig. 3). The average size of mola varied between 3 to 7.5 g. Total fish production from carp-mola polyculture ponds averaged 2831 kg/ha, with 24% of farmers reaching 2501-3000 kg/ha (Table 3). Mola contributed an average of 9% to the total fish production from carp-mola polyculture ponds, reaching a maximum contribution of up to 26%.

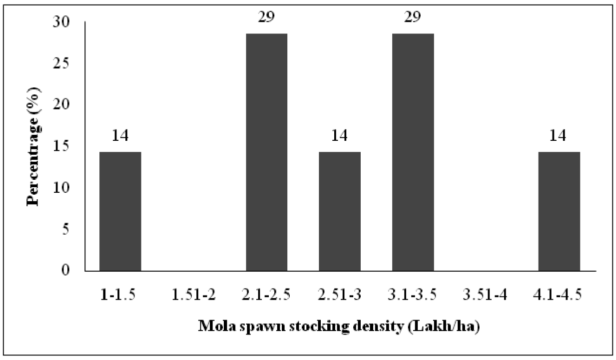

Fig. 1. Frequency distribution of stocking density (Lakh/ha) of mola spawn.

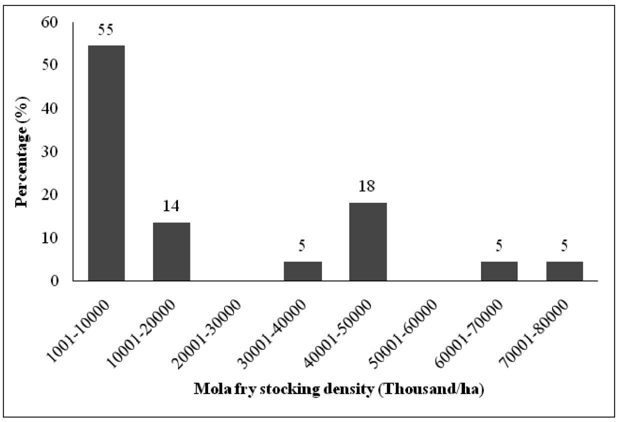

Fig. 2. Frequency distribution of stocking density (Thousand/ha) of mola fry.

Mola was sold at an average price of 146 ± 13.52 INR/kg, with the majority of farmers selling at prices ranging from 140-150 INR/kg. On average, farmers earned an additional INR 19,681 per hectare from mola sales, translating to INR 7,354 per household (Table 3 and Fig. 4). Income disparities were observed, as 38% of farmers earned less than

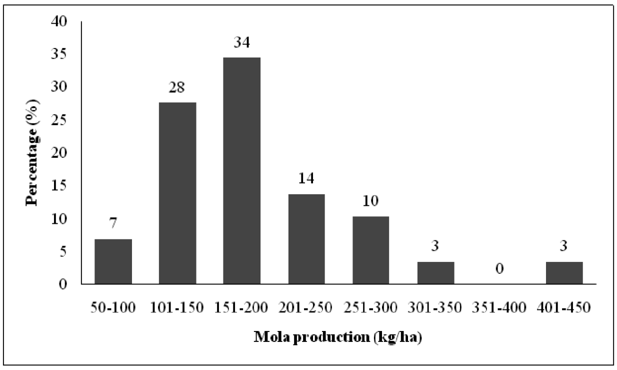

Fig. 3. Frequency distribution of mola production (kg/ha) through hatchery-produced mola seed.

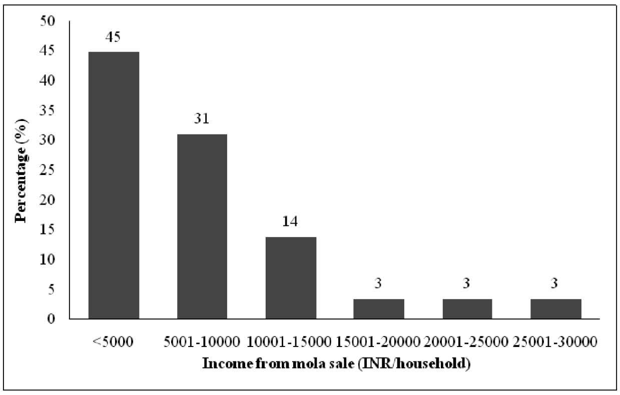

Fig. 4. Frequency distribution of total income from mola sale per household from carp-mola polyculture ponds.

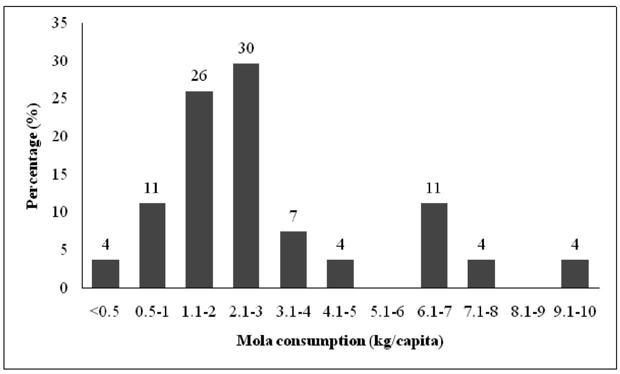

Fig. 5. Frequency distribution of per capita mola consumption (kg/person).

INR 15,000-20,000 per hectare from mola, while 45% earned less than INR 5,000/household.

In the reporting year, each household, on average, consumed 14 kg of mola, ranging from 4 to 40 kg (Table 3). A majority of households (55%) consumed less than 10 kg of mola, while 21% consumed between 11 and 20 kg. Taking into account the surveyed households' average family size of 5.74 ± 3.04, the per capita mola consumption was calculated at 3.04 ± 2.45 kg per year. Over half of the surveyed households consumed mola at the rate of 1-3 kg/capita/year (Fig. 5).

Tables 4 and 5 present the results of Spearman rank correlation, examining key outcome variables, such as mola and total fish production, sale, income, and mola consumption, in relation to various influencing factors recorded as continuous variables. These factors include the age of the farmer, household size, pond size, stock density, distance between the pond and hatchery, and culture duration. The analysis is conducted at both the household level and on a per-hectare basis.

A positive and statistically significant correlation (P<0.01) was found between pond size and mola production, total fish production, income, and consumption of mola at the household level (Table 4). This suggests that an increase in pond size beyond existing levels is linked to higher mola production, income, and household consumption. Culture duration exhibited a significant positive effect (P<0.01) on household-level mola consumption, possibly due to fish remaining in the pond for

Table 4. Spearman rank order correlation (rho) between key outcome variables and influencing factors of carp-mola polyculture production system (household level).

Variables N=29	Mola production (kg/household)	Total fish production (kg/household)	Mola sale (kg/household)	Income from mola sale (INR/household)	Mola consumption (kg/household)
Age of farmer	0.046	0.0466	-0.0608	-0.1054	0.0274
Household size	-0.1417	-0.1346	-0.0659	-0.0851	0.0416
Pond size (ha)	**0.9195*** **	**0.8663*** **	**0.9147*** **	**0.9039*** **	**0.5600*** **
Mola stock density (numbers/ha)	0.084	-0.0933	0.1259	0.0974	0.3662
Distance between pond and hatchery (km)	-0.0531	0.0149	0.0223	-0.1395	0.0726
Culture duration (months)	0.3294	0.2632	**0.4527** **	**0.4425** **	**0.5733*** **

Note: *** and ** indicate Significant at 1% and 5% level

Table 5. Spearman rank order correlation (rho) between key outcome variables and influencing factors of carp-mola polyculture production system (per ha level).

Variables N=29	Mola production (kg/ha)	Total fish production (kg/ha)	Mola sale (kg/ha)	Income from mola sale (INR/ha)
Age of farmer	0.0056	-0.088	-0.0742	-0.0785
Household size	-0.0076	0.049	0.1526	0.0755
Pond size (ha)	0.0582	0.1435	0.2155	0.1698
Mola stock density (numbers/ha)	**0.3926** **	0.0593	**0.4428** **	0.3084
Distance between pond and hatchery (km)	-0.0456	0.0881	0.1432	-0.1325
Culture duration (months)	**0.4601** **	0.0654	**0.4601** **	**0.3946** **

Note: *** and ** indicate Significant at 1% and 5% level.

an extended period, allowing more frequent harvesting (Table 4). Increasing stock density demonstrated a positive and statistically significant effect (P<0.05) on the sale and production of mola per hectare (Table 5). Although stocking hatchery-reared mola seed did not significantly impact total fish productivity (kg/ha), the association remains statistically significant. Table 5 further indicates that culture duration significantly affects per-hectare mola production, sale, and income (P<0.05).

The age of the farmer, often considered a proxy for experience, demonstrated no significant correlation with the outcome variables. Similarly, household size did not exhibit noteworthy associations. Theoretical expectations proposed a negative influence of greater distance on mola production, sale, consumption, and income. However, in our case, this relationship was not statistically significant, except for household-level production and income.

This study provides insights into the performance of hatchery-produced mola seed in homestead carp polyculture ponds, offering valuable contributions to the ongoing efforts in promoting nutrition-sensitive aquaculture. The successful development of a technical protocol for hatchery-based induced breeding and mass seed production of mola in 2022 represents a significant milestone. Subsequent implementation involved the sale or distribution of mola spawns or hatchlings and fry to carp farmers, with a follow-up survey conducted in 2023 to gauge the production potential of hatchery-produced mola seed in homestead carp polyculture ponds.

The partner hatchery's sale of 1.23 million seeds generated revenue equivalent to INR 40,250, directly contributing to farmers' income. Mola production, averaging 194 kg/ha, made a substantial contribution of up to 26% to total fish production. Farmers earned an average of 19,681 INR/ha from mola sales, with each household consuming an average of 14 kg of mola annually, translating to a per capita consumption of 3 kg/year. Notably, mola production through hatchery-produced seed surpassed that from GP tanks in Odisha using wild broodstock (Padiyar et al., 2021), indicating the potential for sustained household consumption and income.

Several experimental studies have been conducted on the polyculture of mola and other SIS with carps and yielded varying degrees of success (Wahab, Rahman, & Milstein, 2002; Wahab et al., 2003; Alim, Wahab, & Milstein, 2004, 2005; Gupta & Rai, 2011). Importantly, the integration of SIS in polyculture has proven to be a viable and profitable concept, avoiding reductions in cash crops like carp production. This system showcases no dietary overlapping or species competition, emphasizing resource sharing and niche utilization among different species. These benefits highlight the potential of polyculture with SIS as an effective and sustainable approach to maximize productivity without compromising other farming aspects.

It has been suggested that introducing the phytoplankton-grazing mola could reduce the availability of food and plankton resources, potentially affecting species like rohu and catla. The impact of mola on carp species in polyculture systems has shown both negative and positive effects (Wahab et al., 2003). The potential negative impact on rohu may stem from competition for food resources. However, studies consistently show that the yields of large carps remain unaffected, indicating that the presence of small fish like mola does not negatively influence the production of these high-value carp species (Wahab et al., 2003; Alim et al., 2005; Kadir, Wahab, Milstein, Hossain, & Seraji, 2007). In fact, increasing the stocking density of large carps neither impacts their survival nor diminishes the amount of mola available for household consumption (Alim et al., 2005).

In polyculture systems, complex interactions occur among different trophic levels, including the pond surface, water column, and bottom layers. These interactions involve both inter- and intraspecific competition, which can result in trade-offs between species, leading to no significant differences in total harvested biomass across treatments (Wahab et al., 2003; Alim et al., 2005; Kadir et al., 2007). However, in well-managed ponds, regular fertilization and supplementary feeding help maintain plankton production, ensuring adequate food availability and reducing competition between species.

To further mitigate competition between mola and carps, farmers can adopt a strategy of systematic partial harvesting. After three months, selective harvesting of adult mola can be done while leaving juveniles in the pond to continue breeding. This allows farmers to harvest mola and other SIS as needed. While the harvested quantities of mola may appear modest, they are vital for household nutrition. In countries like Bangladesh, where SIS like mola or small barbs (*Puntius* spp.) are staple foods, a weekly harvest of just 250 grams of these SIS can provide essential nutrients for a family of five to six members (Wahab et al., 2003).

Pond size demonstrated a significant positive correlation with mola production, income, and consumption, suggesting that an increase in pond size beyond existing levels is associated with higher outcomes. Increased stocking density positively influenced sales and production per hectare, emphasizing the importance of stocking practices. Culture duration exhibited a significant positive effect on household-level consumption, attributed to the prolonged presence of mola in the pond through auto-breeding, allowing for more frequent harvesting. A multitude of factors influence the productivity of mola within carp–mola polyculture ponds such as the quality of stocked broodfish, the presence of predatory fish, stocking density, the composition of carp species, pond size, fertilization levels and climatic conditions (Ali et al., 2016; Rajts & Shelley, 2020). In the present study, the positive correlations observed in pond size, stock density, and culture duration emphasize the potential for optimizing mola production and consumption in homestead carp polyculture ponds. These findings contribute valuable insights to the broader promotion of mola as a farmed species, emphasizing the continued need for research and implementation in addressing food insecurity through sustainable aquaculture practices.

However, this study has several limitations. It was conducted on a pilot basis, aiming to assess the introduction of mola seed into existing carp culture practices under field conditions, without undertaking a comprehensive comparative analysis. To gain a deeper understanding of carp-mola polyculture, more systematic and controlled scientific trials are needed. These future studies should consider factors such as different stocking densities, species compositions, feeding regimes, and water quality parameters. Such an approach would provide a more detailed and nuanced understanding of the system. Besides mola, inclusion of other important nutrient-dense SIS such as pool barb (*Puntius sophore*) or swamp barb (*Puntius chola*) into carp polyculture system should be tested. Despite its limitations, this study serves as a valuable baseline for future research efforts.

In conclusion, the successful execution of hatchery-based mola seed production technology presents a promising avenue for scaling up nutrition-sensitive aquaculture. Carp-mola polyculture offers a holistic approach to sustainable aquaculture, enhancing the productivity of high-value carp species for commercial purposes while providing nutrient-dense small fish for household consumption. This integrated method not only boosts overall fish production but also significantly improves the nutritional quality of the output, making it a promising innovation for combating undernutrition in fish-dependent communities.

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