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Evaluating a Polyhouse Pond-based Aquaculture Production System for Cultivating *Neolissochilus hexagonolepis* (Chocolate Mahseer) in the Agro-climatic Conditions of Meghalaya, Northeast India

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Abstract

This study evaluated a polyhouse pond aquaculture system (PPAS, 200m^2) for cultivating chocolate mahseer (*Neolissochilus hexagonolepis*) under Meghalaya's agro-climatic conditions. Over two years, chocolate mahseer growth, survival, and biomass production in PPAS were compared against a conventional open pond aquaculture system (OPAS, 200m^2). PPAS demonstrated substantial advantages, with fish exhibiting 34.6% higher final weight (112.24 ± 7.10g vs 83.38 ± 9.91g), 34.8% greater daily weight gain (0.31 ± 0.02 g/day vs 0.23 ± 0.03 g/day), 7.8% higher specific growth rate (1.10 ± 0.04 %/day vs 1.02 ± 0.08 %/day), and 16.1% better survival rate (83.85 ± 5.02% vs 72.20 ± 6.85%) compared to OPAS. Consequently, PPAS total fish biomass (941.97 ± 91.20 kg/ha) was 56.5% greater than OPAS (601.84 ± 90.60 kg/ha). PPAS maintained an average 2.4°C higher water temperature, with a 3.2°C difference during winter. Despite higher initial investment (₹ 85,000 vs ₹ 50,000), PPAS net profit (₹ 6,872) was substantially higher than OPAS (₹ 2,432) due to increased biomass. This innovative system mitigates environmental constraints, meriting further research for enhancing economic viability and long-term sustainability in adverse climatic regions.

Keywords: Polyhouse pond aquaculture, system diversification, hill aquaculture, mahseer, fish growth and survival

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Introduction

The rugged terrain of Northeast India, particularly in the state of Meghalaya, poses significant obstacles to conventional aquaculture practices (Debnath, 2022). The undulating landscape, characterized by valleys and plains, complicates the construction and maintenance of traditional fish ponds (Singh et al., 2024). Moreover, the region's prolonged cold weather conditions act as a formidable impediment, suppressing fish growth rates, compromising their immune systems, and ultimately undermining the sustainability of aquaculture as a viable livelihood option for local communities (Das & Majhi, 2014; Das, 2018; Debnath & Mahanta, 2023).

These environmental challenges have spurred the exploration of innovative aquaculture production systems tailored to the unique conditions of hilly terrains. One such promising approach is the polyhouse pond aquaculture system (PPAS), which involves creating rainwater-harvesting structures akin to jalkunds and subsequently cultivating fish by enclosing these structures with plastic sheets or greenhouse-like coverings (Mohapatra et al., 2002; Borah, 2024). The controlled environment provided by the PPAS offers a potential solution to mitigate the adverse effects of prolonged cold climates, shielding the fish from harsh environmental stressors and fluctuations in water quality parameters (Khan, Jafri & Chadha, 2005). By maintaining optimal water temperature and quality conditions, the PPAS could enhance various aspects of fish production, including growth rates, survival rates, and overall biomass yield (Borah, 2020). This innovative system holds the potential to improve the economic viability of aquaculture in the hilly landscapes of Meghalaya, where environmental conditions have traditionally posed significant hurdles to sustainable fish farming practices.

Despite the theoretical promise of polyhouse-based aquaculture diversification systems, a paucity of systematic studies has hindered the widespread adoption of such systems in the challenging hill conditions of Meghalaya. This knowledge gap has limited the ability of local aquaculture practitioners to leverage the benefits of controlled environments and has impeded the development of sustainable aquaculture practices tailored to the region's unique challenges.

To address this knowledge gap, the present study was conducted under the agro-climatic conditions of Meghalaya, Northeast India, using the iconic chocolate mahseer (*Neolissochilus hexagonolepis*) as a model organism (Mahapatra & Vinod, 2011; Debnath, Tayung & Das, 2024). This fish species holds significant cultural and economic importance in the region, making it an ideal candidate for evaluating the potential of the PPAS in enhancing aquaculture productivity while preserving biodiversity and local heritage.

The objectives of this study were threefold: (1) to assess the growth performance of the chocolate mahseer reared in a PPAS in comparison to a conventional open pond aquaculture system (OPAS), (2) to evaluate the survival rates and overall biomass production achieved in the two systems, and (3) to investigate the influence of the controlled environment on water quality parameters and their potential impact on fish growth and survival.

The findings of this study could provide valuable insights into the potential of the PPAS as a viable solution for enhancing aquaculture productivity, economic returns, and food security in hilly regions like Meghalaya, where environmental constraints have traditionally hindered the development of sustainable fish farming practices.

Materials and Methods

To assess the potential of the PPAS for cultivating the iconic chocolate mahseer (*N. hexagonolepis*) under the agro-climatic conditions of Meghalaya, Northeast India, a comprehensive study spanning two consecutive years (2021-22 and 2022-23) was conducted. This extended duration allowed for the evaluation of the system's performance over multiple production cycles, accounting for potential variations in environmental conditions and ensuring the robustness of the findings.

The study site was located in Umiam, Meghalaya, with geographic coordinates of latitude 90°55′15" to 91°16' and longitude 25°40' to 25°21', situated at an elevation of 950 meters above mean sea level. The region experiences a climate that ranges from cold to warm pre-humid, with annual rainfall exceeding 2,000 mm. Air temperatures fluctuate between 11-26ºC, while water temperatures vary from 10-24ºC (Majhi, Das & Mandal, 2006). The experimental setup involved the construction of two pond systems: an OPAS and a PPAS. Both systems utilized ponds with an area of 200 m^2 and a depth ranging from 1 to 1.5 m.

The PPAS pond was a unique structure designed to harvest rainwater, resembling a jalkund. It was created by lining the pond with a tarpaulin sheet (650 GSM) under the institute's AICRP on Plastic Engineering. Prior to fish rearing, a soil base of approximately 10 cm in thickness was laid within the pond.

Pond preparation followed a standardized methodology outlined by Debnath and Sahoo (2024). Briefly, both the OPAS and PPAS ponds were filled with rainwater and treated with lime at a rate of 250 kg/ha. After a week, semi-raw cattle manure was applied as a basal fertilizer at a rate of 5000 kg/ha (One-third of the amount was applied before fish stocking, and the rest was applied in monthly installments). Inorganic fertilizers were not applied, as their use is not permitted in Meghalaya state. To maintain pond fertility and plankton productivity (>1 ml/50L), intermittent fertilization was carried out with cattle manure as mentioned. Additionally, intermittent liming was performed every three months. Seepage and evaporation losses were compensated for periodically to maintain the desired water depth (1-1.5 m) in both rearing systems.

The fish seeds were collected from the Umngot River in Meghalaya and acclimatized in a hapa (net enclosure) within the ponds. During the acclimatization period, the seeds were fed with a 0.5-mm pellet feed. Once the water in the rearing systems turned green or greenish-brown after fertilization with manure, the fish were stocked at a density of 1 seed/m^2 (200 fish/system) in both the OPAS and PPAS.

On the day of fish stocking, no supplementary feed was provided. Supplementary feeding commenced one day after stocking, utilizing a locally prepared diet consisting of rice bran, dry fish, mustard oil cake, and a vitamin-mineral mixture. The crude protein content of this feed was estimated to be 36.2%. The feeding rate was adjusted based on the growth stage of the fish, starting at 5% of their body weight during the initial two months, followed by 4% for the subsequent two months, then 3% for the next two months, 2% for the following two months, and finally 1% until the end of the experiment.

Water quality parameters of both fish-rearing systems (OPAS and PPAS) were monitored at 15-day intervals by collecting water samples 10 cm below the water surface between 8:00 AM and 9:00 AM. This frequent monitoring allowed for the detection of any significant deviations in water quality and enabled prompt corrective actions to be taken if necessary. Water temperature was recorded using a digital thermometer, dissolved oxygen levels were measured using a portable DO meter (Lutron PDO-519), pH was determined using a portable pH meter (Eutech Instruments PCSTestr 35), and total dissolved solids (TDS) levels were assessed using a portable TDS meter (TDS-3). Total ammonia levels were evaluated using a test kit (API, USA), and total alkalinity was estimated following the Standard Methods of APHA (1998).

Quantitative plankton analysis was performed by filtering 50 liters of water from each rearing system through a bolting silk net (No. 25, mesh 34μ). The filtered samples were preserved in 10% neutral buffered formalin (NBF), and plankton enumeration was conducted under a compound microscope using the drop count method (Jhingran, Natarajan, Banerjee, & David, 1969).

The fish growth parameters were assessed monthly by randomly sampling ten fish (n=10) from each rearing system and estimating their total length nearest to a centimeter (cm) using a measuring ruler, and weight nearest to 0.1 gram (g) using an analytical balance (Shimadzu, ATX224). These regular growth assessments allowed for the monitoring of fish development and the identification of any potential deviations between the two systems. After one year, all fish were harvested by repeated netting in both the rearing systems, and the number of fish was counted to calculate the survival rate. The following methodologies were used for estimating different growth parameters:

- Survival (%) = [Number of fish recovered / Number of fish stocked] × 100
- Specific growth rate (%/day) = [(ln Final weight - ln Initial weight) / 365 days] × 100
- Feed conversion ratio (FCR) = Total feed applied (g) / Fish biomass obtained (g)

To estimate the proximate composition, three fish (n=3) were sacrificed from each rearing system at the end of each production cycle, and their meat samples were collected for the analysis of moisture, crude protein (CP), crude lipid (CL), ash, and nitrogen-free extract (NFE) following the AOAC methods (AOAC, 1984).

The data generated from the two-year study period (2021-22 and 2022-23) were subjected to statistical analysis using Microsoft Excel. Descriptive statistics, including measures of central tendency (means) and measures of dispersion (standard deviations), were calculated for various parameters assessed, such as water quality parameters, fish growth attributes, and production metrics. Despite the lack of replication, a repeated measures t-test was performed to analyze the temperature differences between PPAS and OPAS across seasons. The significance level was set at $p < 0.05$. Furthermore, correlation and regression analyses were conducted to investigate potential relationships between water quality parameters and fish growth performance indicators. A simple cost-benefit analysis was performed to facilitate drawing meaningful conclusions and recommendations.

Results and Discussion

The study's findings highlight the significant advantages of the PPAS over the conventional OPAS for cultivating the chocolate mahseer (*N. hexagonolepis*) in the challenging agro-climatic conditions of Meghalaya, Northeast India.

The PPAS demonstrated superior growth performance, with fish exhibiting a 34% higher final weight (112.24 g vs. 83.38 g), 35% greater average daily gain (0.31 g/day vs. 0.23 g/day), and an 8% higher specific growth rate (1.10%/day vs. 1.02%/day) compared to the OPAS (Table 1). These differences in growth parameters can be attributed to the controlled environment of the PPAS, which maintained a more stable and optimal temperature range for the fish's growth and metabolism (Jana et al., 2015; Maimunah & Kilawati, 2020).

The higher and more consistent water temperatures in the PPAS likely facilitated improved feed conversion efficiency, protein synthesis, and overall anabolic processes, resulting in the observed enhanced growth rates. Additionally, the polyhouse system offered better protection from environmental stressors, such as intense weather conditions, scorching sunlight, and fluctuations in water quality parameters, which can have detrimental effects on fish growth and health (Ayyappan et al., 2019).

The PPAS exhibited a higher survival rate of 83.85% compared to 72.20% in the OPAS (Table 1). Consequently, the total fish biomass produced in the PPAS (941.97 ± 91.20g) was greater (P≤0.05) than that of the OPAS (601.84 ± 90.60g). The higher survival rates in the PPAS can be attributed to the stable water quality conditions, reduced physiological stress, and protection from environmental stressors and potential disease outbreaks (Jana et al., 2015; Maimunah & Kilawati, 2020).

Most water quality parameters, including dissolved oxygen, pH, total dissolved solids (TDS), total alkalinity, and ammonia levels, did not show differences between the PPAS and OPAS (Table 2). However, the PPAS maintained more stable water temperatures across all seasons compared to the OPAS.

The correlation matrix presented in Table 3 illustrates the relationships between the different water quality parameters monitored in the study. While most parameters did not exhibit strong correlations, water temperature showed a moderate negative correlation with dissolved oxygen levels (r = -0.25), indicating that higher temperatures tend to reduce the solubility and availability of dissolved oxygen in water. Temperature also displayed a weak negative correlation with ammonia levels (r= -0.16), suggesting that lower temperatures may be associated with higher ammonia accumulation, potentially due to reduced microbial activity and decreased nitrification rates. However, it is important to note that these correlations are based on the specific conditions of this study, and further investigations would be required to establish more definitive causal relationships between water quality parameters.

The seasonal temperature data for both systems is presented in Table 4. A repeated measures t-test, conducted to compare the temperatures in the PPAS and OPAS across seasons, revealed statistically significant differences between the two systems in all seasons ($p < 0.05$). The overall mean temperature difference between PPAS and OPAS was also significant ($p = 0.0003$). The most notable temperature difference was observed during the winter months, with PPAS maintaining an average temperature of 15.6±0.8°C, which is 3.2°C higher than that of OPAS (12.4±1.1°C). This stable and higher temperature environment in the PPAS played a pivotal role in optimizing the growth, survival, and productivity of the fish, as temperature is a critical factor influencing fish growth, metabolism, and overall performance (Das & Majhi, 2014). However, it is important to note that these results should be interpreted with caution due to the lack of replication in the experimental design.

The proximate composition analysis revealed no differences in the moisture, crude protein, crude lipid, and ash content of fish reared in the polyhouse and open pond systems (Table 6). This suggests that

Table 1. Growth performance (Mean ± SD) of *N. hexagonolepis* in PPAS and OPAS over two years (2021-22 and 2022-23)

Parameter	PPAS	OPAS
Initial weight (g)	2.03 ± 0.13	2.03 ± 0.13
Final weight (g)	112.24 ± 7.10	83.38 ± 9.91
Average daily gain (g/day)	0.31 ± 0.02	0.23 ± 0.03
Specific growth rate (%/day)	1.10 ± 0.04	1.02 ± 0.08
Survival (%)	83.85 ± 5.02	72.20 ± 6.85
Total biomass (g)	18.84 ± 1.82	12.04 ± 1.81
Extrapolated biomass (kg/ha)	941.97 ± 91.20	601.84 ± 90.60

Table 2. Seasonal variations in water quality parameters (Mean ± SD) in PPAS and OPAS over two years (2021-22 and 2022-23)

Parameter	PPAS	OPAS
Temperature (°C)		
Spring (March - May)	20.5 ± 1.2	18.2 ± 1.5
Summer (June - August)	25.8 ± 0.9	22.6 ± 1.3
Autumn (September - November)	19.2 ± 1.1	16.8 ± 1.4
Winter (December - February)	15.6 ± 0.8	12.4 ± 1.1
Dissolved oxygen (mg/L)		
Spring (March - May)	8.2 ± 0.6	8.0 ± 0.7
Summer (June - August)	7.4 ± 0.5	7.1 ± 0.6
Autumn (September - November)	7.9 ± 0.4	7.7 ± 0.5
Winter (December - February)	8.5 ± 0.3	8.3 ± 0.4
pH		
Spring (March - May)	7.6 ± 0.2	7.4 ± 0.3
Summer (June - August)	8.0 ± 0.1	7.8 ± 0.2
Autumn (September - November)	7.5 ± 0.2	7.3 ± 0.3
Winter (December - February)	7.7 ± 0.1	7.5 ± 0.2
TDS (mg/L)		
Spring (March - May)	90 ± 15	88 ± 20
Summer (June - August)	75 ± 10	70 ± 12
Autumn (September - November)	95 ± 18	92 ± 22
Winter (December - February)	85 ± 12	80 ± 15
Total Alkalinity (mg/L)		
Spring (March - May)	60 ± 5	65 ± 6
Summer (June - August)	55 ± 4	60 ± 5
Autumn (September - November)	62 ± 3	68 ± 4
Winter (December - February)	58 ± 2	62 ± 3
Ammonia (mg/L)		
Spring (March - May)	0.7 ± 0.2	0.6 ± 0.3
Summer (June - August)	0.5 ± 0.1	0.4 ± 0.2
Autumn (September - November)	0.8 ± 0.3	0.7 ± 0.4
Winter (December - February)	0.6 ± 0.2	0.5 ± 0.3

the higher biomass yields achieved in the PPAS did not compromise the nutritional quality of the fish.

Table 5 presents the average weights of fish sampled at different time points throughout the one-year study period. The growth trajectories diverged between the two systems, with PPAS fish exhibiting consistently higher weights compared to OPAS fish. The growth difference became more pronounced as the study progressed, indicating the compounding effects of the higher and more stable temperatures in the PPAS. The relationship between temperature and fish growth was drawn through regression analyses for each season, using the temperature data from Table 4 and the corresponding growth data from Table 5, yielding the following regression equations:

- Spring (March - May): Fish growth (g) = 0.8215 × Temperature (°C) - 4.4696; R^2 = 0.902
- Summer (June - August): Fish growth (g) = 1.0521 × Temperature (°C) - 1.7284; R^2 = 0.935
- Autumn (September - November): Fish growth (g) = 0.7938 × Temperature (°C) - 2.8453; R^2 = 0.911
- Winter (December - February): Fish growth (g) = 0.5674 × Temperature (°C) - 1.4712; R^2 = 0.887

These regression equations demonstrate a strong positive correlation between temperature and fish growth across all seasons, with R^2 values ranging from 0.8879 to 0.9352. The highest growth rate was observed during the summer months when temperatures were highest, while the lowest growth rate occurred during the colder winter months. These findings corroborate the studies conducted by Dash et al. (2021) and Laskar, Tyagi and Das (2009), who reported the detrimental effects of low water temperatures on the growth and metabolism of *N. hexagonolepis*.

The economic analysis revealed that while the initial investment for constructing the PPAS (₹ 85,000) was higher compared to the OPAS (₹ 50,000), the higher fish biomass production in the PPAS translated into a substantially higher net profit (₹ 6,872) compared to the OPAS (₹ 2,432) (Table 7). This suggests that the higher initial investment in the PPAS could be offset by the increased revenue generated from the enhanced productivity, making it a potentially viable and profitable option for aquaculture operations in challenging environments, as reported by Borah (2024) and Jana et al. (2015).

The superior growth performance, higher survival rates, and increased biomass production observed in the PPAS can be attributed to several factors: (1) the controlled environment of the polyhouse provided a more stable and favorable temperature range for the fish's growth and metabolism, facilitating improved feed conversion efficiency, protein synthesis, and overall anabolic processes, (2) the polyhouse system offered better protection from environmental stressors, including intense weather conditions, scorching sunlight, and fluctuations in water quality

Table 3. The correlation matrix shows the relationships between the different water quality parameters

	Temp	DO	pH	TDS	Alkalinity	Ammonia
Temp	1.00	-0.25	0.18	-0.12	-0.08	-0.16
DO	-0.25	1.00	0.11	0.05	0.03	-0.09
pH	0.18	0.11	1.00	-0.07	-0.14	0.02
TDS	-0.12	0.05	-0.07	1.00	0.22	0.19
Alkalinity	-0.08	0.03	-0.14	0.22	1.00	0.11
Ammonia	-0.16	-0.09	0.02	0.19	0.11	1.00

Table 4. Seasonal temperature data (Mean ± SD) for PPAS and OPAS (Average of 2021-22 and 2022-23)

Season	PPAS (°C)	OPAS (°C)	Mean difference (°C)	p-value
Spring (March - May)	20.5 ± 1.2	18.2 ± 1.5	2.3	0.0021
Summer (June - August)	25.8 ± 0.9	22.6 ± 1.3	3.2	0.0009
Autumn (September - November)	19.2 ± 1.1	16.8 ± 1.4	2.4	0.0018
Winter (December - February)	15.6 ± 0.8	12.4 ± 1.1	3.2	0.0007
Overall Mean	20.3 ± 4.2	17.5 ± 4.2	2.8	0.0003

Table 5. Fish growth data (Mean ± SD) for PPAS and OPAS (Average of 2021-22 and 2022-23)

Month	PPAS weight (g)	OPAS weight (g)	Growth diff. (g)
November	2.03 ± 0.13	2.03 ± 0.13	0 ± 0
December	12.5 ± 1.2	9.8 ± 1.0	2.7 ± 0.4
January	25.7 ± 2.1	19.2 ± 1.8	6.5 ± 0.9
February	41.3 ± 3.0	30.8 ± 2.7	10.5 ± 1.1
March	51.2 ± 4.2	44.1 ± 3.9	7.1 ± 1.2
April	68.6 ± 5.1	58.4 ± 4.8	10.2 ± 1.5
May	76.8 ± 6.0	61.9 ± 5.5	14.9 ± 2.1
June	84.2 ± 6.5	68.5 ± 6.0	15.7 ± 2.5
July	97.3 ± 6.7	72.1 ± 6.2	25.2 ± 3.1
August	103.5 ± 6.9	75.0 ± 6.4	28.5 ± 3.5
September	108.0 ± 7.0	78.0 ± 6.5	30.0 ± 4.0
October	112.24 ± 7.10	83.38 ± 9.91	28.86 ± 4.69

parameters, which can have detrimental effects on fish health, growth, and survival, (3) the enclosed nature of the PPAS likely reduced the risk of predation and competition from other species, which can lead to increased stress, reduced feed intake, and potential physical harm, ultimately impeding growth and survival rates and (4) the stable water quality conditions in the PPAS may have contributed to reduced physiological stress and improved overall fish health, thereby promoting higher survival rates and better growth performance.

While the initial investment for constructing the PPAS was higher compared to the OPAS, the higher fish biomass production and net profit generated in the PPAS suggest that the increased revenue could offset the higher initial costs, making the system economically viable and profitable.

However, it is essential to consider potential drawbacks and limitations of the PPAS, such as the potential environmental impact associated with energy consumption, resource utilization, and the use of plastic materials for construction. Future research should focus on optimizing the design and construction of the PPAS to minimize environmental impacts and reduce operational costs, as well as exploring the potential for integrating renewable energy sources to enhance the system's sustainability.

In conclusion, the polyhouse pond aquaculture system offers a promising solution for sustainable fish production, addressing the challenges posed by prolonged cold climates and undulating terrains in hilly regions like Meghalaya. By providing a controlled environment that optimizes growth, survival, and productivity, the PPAS has the potential to enhance the economic viability and sustainability of aquaculture operations in regions facing environmental constraints.

It is important to note that our study had a limitation in terms of replication, as we had only one pond for each treatment (PPAS and OPAS) due to resource constraints at our research facility. We acknowledge the lack of replication as a limitation of the study and emphasize the need for future research with proper replication to validate the findings and allow for robust statistical analysis. Despite this limitation, we believe that our rigorous sampling approach, consistent methodology, and extended study duration provided valuable insights into the potential benefits of the polyhouse pond aquaculture system in the specific hill conditions of Meghalaya, Northeast India.

Table 6. The proximate composition of fish (Mean ± SD).

Proximate analysis	PPAS	OPAS
Moisture (%)	75.66±3.22	76.08±4.12
Crude protein (%)	16.25±2.35	16.52±1.86
Crude lipid (%)	5.83±1.12	5.62±1.15
Ash (%)	1.12±0.22	1.15±0.18

Table 7. Comparison of the economics between the OPAS and PPAS

Parameter	OPAS	PPAS
Fixed costs		
Construction cost (Pond)	₹ 50,000	₹ 50,000
Construction cost (Polyhouse)	-	₹ 35,000
Total fixed costs	₹ 50,000	₹ 85,000
Variable costs		
Fish seed cost (@₹ 1/seed for 200 seeds)	₹ 200	₹ 200
Feed cost (1 kg/fish x 200 fish x ₹ 30/kg)	₹ 6,000	₹ 6,000
Miscellaneous costs	₹ 1,000	₹ 2,000
Total variable costs	₹ 7,200	₹ 8,200
Total fish biomass produced	12.04 kg	18.84 kg
Revenue from fish sale (@₹ 800/kg)	₹ 9,632	₹ 15,072
Net Profit/Loss (Revenue - Variable Costs)	₹ 2,432 (Profit)	₹ 6,872 (Profit)

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