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Original research article

The effects of stocking density on the growth and survival of hybrid Catfish in cage culture environments

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ABSTRACT

The cultivation of hybrid catfish at high stocking densities within cage environments is considered for its potential to enhance production efficiency. This study, employing a completely randomized design with four treatments and three replications, was conducted to assess the impact of varying stocking densities on growth parameters and survival rates. The treatment (Trt) groups were established based on different stocking densities, defined as the number of fish/m^3 of cage. These groups included Trt1 with 5 fish/m^3, Trt2 with 10 fish/m^3, Trt3 with 15 fish/m^3, and Trt4 with 20 fish/m^3. Measurements of specific growth rates and survival rates were analyzed using analysis of variance to determine the effects of stocking densities. The ANOVA results indicated that stocking density significantly influenced both growth rates in specific weight and survival rates. Employing the Duncan multiple range test, it was revealed that Trt1, with the lowest density, exhibited the highest specific growth rate at 615.6 ± 2.8 %/ day. Conversely, the lowest growth rate of 577.1 ± 84.0 %/day was observed in Trt4, which had the highest density. Additionally, the highest survival rate was recorded in Trt1 at 96.3 %, while the lowest was observed in Trt4 at 63.5%. These results demonstrate that lower stocking densities are associated with improved growth and higher survival rates in hybrid catfish, emphasizing the importance of maintaining optimal densities to enhance health and growth efficiency.

Keywords: hybrid catfish, stocking density, cage culture, aquaculture efficiency

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1. Introduction

Cage aquaculture has been extensively adopted globally and significant research has been carried out in various countries. Initiated in the early 1950s in Thailand, cage culture initially employed bamboo cages, which were later substituted by wooden planks due to their ease of construction and management. In the wider context of freshwater aquaculture in Thailand, it was found that cage culture contributed merely 0.3% to the total fish production from rivers and reservoirs, which amounted to 200,000 tons.[1-3] Cage culture is practiced in various aquatic settings, including rivers, reservoirs, irrigation canals, and large ponds, with flowing waters being the predominant habitats. In the past decade, the peak annual fish production from freshwater cages was achieved at 2,700 tons in 1991, but this figure has since declined to 600 tons in 1995. The carrying capacity of aquatic environments has been effectively increased through cage aquaculture. In cage aquaculture, fish stocking density significantly influences growth, survival, health, water quality, and overall production. It is widely acknowledged that high stocking densities can suppress fish growth and elevate mortality rates. While high stocking densities in aquaculture are generally associated with reduced growth and increased mortality due to competition for resources, it is observed that species such as tilapia, carp, and trout can show improved growth, survival, and feed conversion ratios under these conditions. This highlights the species specific nature of aquaculture practices and underscores the importance of management strategies being tailored to optimize conditions for each type of fish.[4-6]

This case bears similarities to the findings presented by Diao et al[6] which suggest a need for a deeper understanding of *Pelteobagrus fulvidraco* responses to varying stocking densities in integrated rice-fish farming systems. It is recommended that the stocking density for *P. fulvidraco* in these systems be maintained below 250 g/m^3, taking into account both growth and physiological responses. Furthermore, in the study conducted by Roy et al.[7] it was revealed that low stocking density induces chronic stress, which in turn alters the physiological responses of trout. This is achieved through the dysregulation of inflammatory and immune systems, as well as indolamine and catecholamine levels in the brain. Considering all observed variables, it has been demonstrated that low stocking density significantly affects the survival, growth, and feed efficiency of rainbow trout, as well as altering their physiological responses. The selection of an appropriate fish density, relative to rearing conditions, is shown to be crucial for improving welfare in aquaculture contexts. Additionally, the prevalence of species such as red snakehead, catfish, marble goby, and tilapia in aquaculture operations underscores their robustness and adaptability to various environmental conditions.[8,9]

In Thailand, hybrid catfish known for their white meat, are second-generation hybrids bred from a male giant catfish (*P. gigas*) and a female striped catfish (*P. hypophthalmus*), both of which are also hybrids of the same species. Catfish, praised for their health benefits, high nutritional value, robust growth, and strong disease resistance, are cultivated successfully in various environments such as earthen ponds and cages.[10] The agricultural production of catfish in Thailand for 2016 was reported at 106,860 tons, showing a decrease from the 111,480 tons recorded in 2015. Annually updated, the data averaged 111,480 tons from December 2014 to 2016, reaching a peak of 113,825 tons in 2014. Despite these figures, it is estimated that the production levels of white meat hybrid catfish are currently inadequate to meet the growing demands. This species is capable of thriving at high stocking densities and can reach marketable size within 6-8 months.[11,12] However, it was determined that the growth of hybrid catfish in cage culture environments is neither suitable nor economically viable. In contrast, superior growth performance was exhibited by Thai pangasius (*P. sutchi*) when it was reared in cage environments and fed a diet consisting of rice bran and mustard oil cake at a satiation rate.[13,14]

2. Materials and Methods

2.1 Selection of study site

The study was conducted from March to June 2024 at a reservoir located at 18.730504N, 100.824526E in Namkian sub-district, Phuphiang district, Nan province, approximately 15 km from the town of Nan. This area was selected for the experiment based on a baseline site suitability survey. The site was deemed well suited for cage culture of hybrid catfish. Measurements such as a water flow rate of 70 ± 1.5 cm/s, pH of 6.5 ± 0.1, dissolved oxygen concentration of 5.6 ± 0.1 mg/L, and temperature of 29.0 ± 0.0 °C were recorded, all of which fall within the prescribed parameters for cage culture of hybrid catfish.

2.2 Experimental animals

Approval for all experimental procedures, animal care, and biosafety measures was granted by Institutional Animal Care and Use Committee for Science Research of Rajamangala University of Technology Lanna (Approval no. RMUTL-IACUC 006/2024) which comply with standard of animal care and use established under the ethical guidelines and policies of office of the National Research Council of Thailand. Hybrid catfish fries (average weight 15.0 g) from the fish farm in Nan province were reared in a hapa enclosure placed in a 200 m³ earthen pond for a period of two weeks. During this rearing period, the fish were fed commercial feed pellets (32% crude protein) at a rate of 5% of body weight twice daily. For an additional 10 days prior to stocking in the experimental cages, the fish were maintained under these conditions. A total of 900 fish, with an average weight of 15.5 ± 0.1g, were stocked at four different densities of 5, 10, 15, and 20 fish/m³.

2.3 Experimental feeds

In this study, the commercial diets containing 32% crude protein were employed, chosen based on the essential nutrients required for satisfactory growth rates in catfish. Feeding was feed twice daily, at 8:00 am and 5:00 pm, using manual feeders until satiation, approximately 3% of body weight per day. The feeding rate and frequency were adopted from protocols used for catfish as reported by Chen et al.[15] and Putra et al.[16] uneaten feed was collected from the cage culture one hour after feeding times. This process was systematically applied to each cage. Fish sampling was carried out every thirty days to adjust the amount of feed administered.

2.4 Experimental design

The experiment was divided into four treatment groups with three replications provided for each group. The treatments (Trt) were defined by the number of fish per cubic meters (fish/m³) of cage, divided into four groups: Trt1 with 5 fish/m³, Trt2 with 10 fish/m³, Trt3 with 15 fish/m³, and Trt4 with 20 fish/m³. Hybrid catfish used in the experiment were obtained from a farm located in Nan province. Each treatment was replicated three times to ensure the reliability and robustness of the experimental data. The fish were stocked in cages, each measuring 6.0 cubic meters, within an earthen pond measuring 15x20x2.0 m and lined with chrome pipe. The basic floating part of the cage measured 2 x3x1 m, and the bottom of the net with a mesh size of 10 mm was stretched with a chrome pipe frame also measuring 2x3x1 m. The top of the cage was covered with a black brand to protect the fish from intense light. For an additional 7 days prior to stocking in the experimental cages, the fish were maintained under these conditions. A total of 900 fish, with an average weight of 24 g/fish, were stocked at four different densities of 5, 10, 15, and 20 fish/m³. Throughout the cultural period, from March to June 2024, no aeration was provided to the fish in any of the culture conditions. At the end of the culture period, thirty fish from each treatment group were randomly selected for sampling.

2.5 Data collection and analysis

Evaluation of growth performance of fish: At the end of the culturing period, fish were sampled and weighed to assess their growth performance. Survival rates were calculated using the method described by Hossain et al[17]; Lim et al[18]; Mustapha et al [19]; Hossain et al[20] which includes three key parameters:

1) average daily gain (ADG, g/fish/day) calculated as:

$$\frac{\text{Final fish weight - Initial fish weight}}{\text{Culture period (days)}}$$

2) percentage of weight gain (PWG, %) calculated as:

$$\frac{\text{Final fish weight - Initial fish weight}}{\text{Culture period (days)}} \text{ x } 100$$

3) specific growth rate (SGR, g/day) calculated as:

$$\frac{\text{ln(final fish weight)-ln(initial fish weight)}}{\text{Culture period (days)}} \text{ x } 100$$

Evaluation of feed conversion ratio of fish: At the end of the culturing period, the feed conversion ratio (FCR) of the fish in this experiment was evaluated using the following formula:

$$\frac{\text{Feed intake}}{\text{Final fish weight-Initial fish weight}}$$

Evaluation of water quality performance: Water quality assessments were conducted four times throughout the experimental period. During this time, while commercial diets were fed to the fish and uneaten food was collected, water exchanges were not performed. The evaluation of water quality performance was rigorously undertaken to ensure the health and sustainability of catfish ecosystems, especially in controlled environments such as aquaculture systems. Systematic monitoring and analysis of various physical and chemical parameters that could impact water quality were involved in this evaluation. Key indicators typically included dissolved oxygen (DO), pH levels, turbidity, water temperature, nitrogenous compounds included ammonia (NH_3) nitrite (NO_2^-) and nitrate (NO_3^-). All water quality parameters were monitored once daily in the morning (08:00 am). Measurements was conducted using sophisticated instruments, such as the Horiba U-50 series water quality meter and the LAQUA twin compact water quality meter. Statistical analyses: All data was expressed as mean ± S.D. and analyzed by one-way ANOVA. The duncan's multiple range Test was used to determine the differences between the treatment means.[21] All statistical tests were conducted at an alpha level of 0.05.

3. Results

3.1 Growth performance of fish

At the conclusion of the culturing period, growth performance parameters of fish in each cultured environment were depicted in Fig.1. Statistical analysis revealed significant differences among the treatment groups concerning the parameter of mean final weight. The initial weights of the fish were documented as follows: 24.3 ± 0.5 g for Trt1, 24.1 ± 0.7g for Trt2, 24.2 ± 0.5 g for Trt3, and 24.3 ± 0.5 g for Trt4. The final body weights were recorded as 484.6 ± 17.0 g for Trt1, 436.6 ± 67.7 g for Trt2, 418.1 ± 35.0 g for Trt3, and 392.2 ± 62.0 g for Trt4. Significant differences were also observed in the average daily gain among the treatment groups at the conclusion of the experiment. The highest ADG was observed in fish from Trt1 at 3.9 ± 0.2 g/fish/day, followed by those in Trt2 at 3.5 ± 0.4 g/fish/day, Trt3 at 3.3 ± 0.3 g/fish/day, and Trt4 at 3.0 ± 0.4 g/fish/day. The lowest specific growth rate (SGR) was recorded in fish cultured in Trt1 at 615.6 ± 12.8 %/day, which was significantly lower than those recorded in Trt2 at 605.5 ± 11.4 %/day, Trt3 at 599.9 ± 11.1 %/day, and

Trt4 at 577.0 ± 14.0 %/day The results from the growth performance analysis of catfish over 120 days revealed that the highest percentage weight gain (PWG) was observed in catfish cultured in Trt1 at 387.0 ± 11.2%, followed by those in Trt2 at 350.1 ± 39.8%, Trt3 at 329.9 ± 37.7%, and Trt4 at 306.5 ± 40.5%. Significant differences were observed among the treatment groups. High survival rates were recorded in catfish cultured in Trt1 at 96.3 ± 0.5%, no significant differences were noted among the treatment groups in terms of survival. The lowest survival was observed in catfish cultured in Trt4 at 63.5 ± 0.5%.

3.2 Feed conversion ratio of fish

At the conclusion of the experiment, significant differences were noted among the treatment groups in terms of feed conversion ratio (FCR). The highest FCR was recorded in catfish cultured in Trt4 at 3.2 ± 0.0, followed by those in Trt3 at 2.8 ± 0.0, and Trt2 at 2.9 ± 0.0. The lowest feed conversion ratio was observed in catfish from Trt1 at 2.6 ± 0.0.

3.3 Water quality performances

Based on the results and statistical analysis presented in Table 1, it was observed that no significant differences were found among the treatment groups regarding various water quality parameters, including dissolved oxygen, pH levels, conductivity, total dissolved solids (TDS), turbidity, and water temperature. The highest dissolved oxygen concentration was recorded at 6.2 ± 0.0 mg/L in Trt1 (5 fish/m^3) while the highest pH levels (6.2 ± 0.0), conductivity (0.2 ± 0.2 ms/cm), TDS (12.0 ± 2.5 mg/L), turbidity (50.2±10.0 NTU), and water temperature (29.1 ± 0.0 °C) were found in Trt4 (20 fish/ m^3). Although Trt4 had the highest turbidity (50.2 ± 10.0 NTU) and salinity (0.1 ± 0.0 ppt), none of these differences were statistically significant. This indicates that varying stocking densities had no significant impact on these water quality parameters. However, significant differences were observed among treatment groups in relation to nitrogenous waste-related parameters, such as un-ionized ammonia, nitrite (NO_2^-), and nitrate (NO_3^-). Nitrogenous waste, primarily generated from fish feed, plays a critical role in nutrient enrichment within aquaculture systems.

The main nitrogenous compounds of concern are un-ionized ammonia (NH_3), ionized ammonia (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). In this study, levels of un-ionized ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-) in catfish cultured under different stocking densities were categorized into four treatment groups: Trt1 (5 fish/m^3) Trt2 (10 fish/m^3), Trt3 (15 fish/m^3), and Trt4 (20 fish/m^3). Significant differences were found among these groups. The highest nitrogenous waste levels, particularly gaseous nitrogen from fish excretion, were observed in Trt4 (20 fish/m^3) and were significantly higher than those in Trt1, Trt2 and Trt3. This suggests that increased stocking density led to greater accumulation of nitrogenous waste in the cultured environments. In conclusion, while most water quality parameters remained stable across different stocking densities, significant increases in ammonia, nitrite, and nitrate levels were observed with higher stocking densities, indicating a negative impact on water quality. This highlights the importance of improved water management practices or reducing stocking densities to maintain optimal water quality in aquaculture systems.

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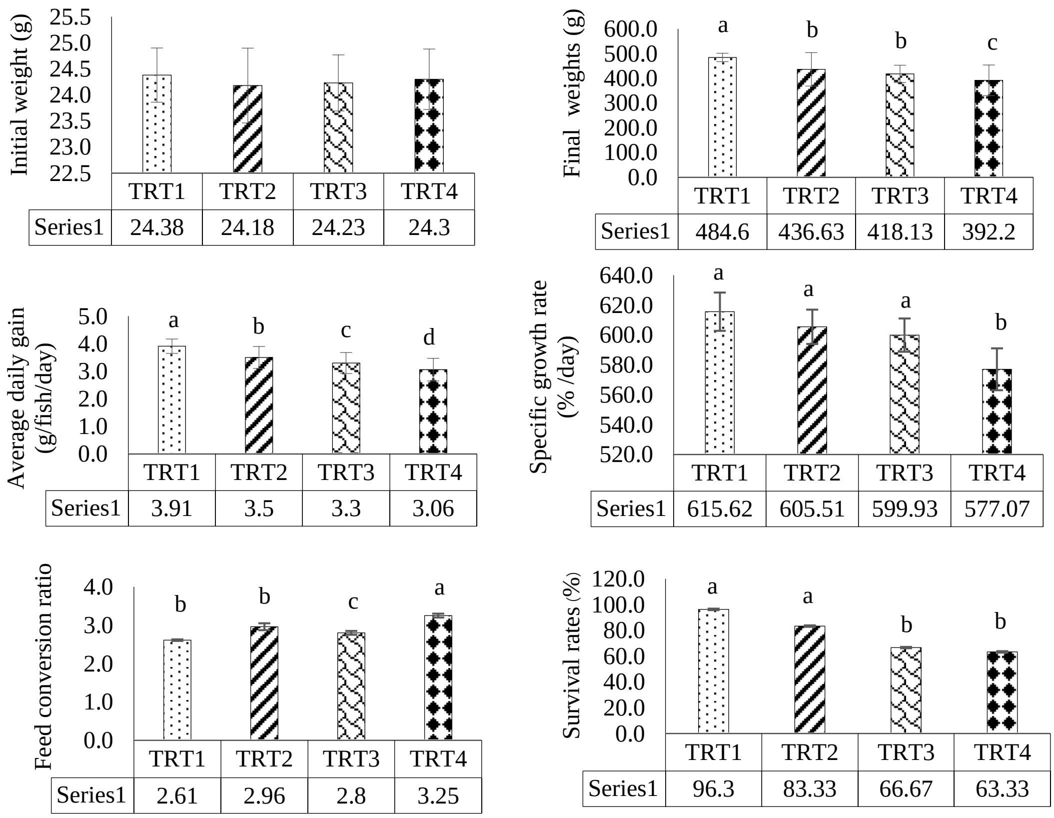

Fig.1. External morphological examination data in hybrid catfish obtained from treatments 1, 2, 3, and 4. These densities were categorized into four groups: Trt1 with 5 fish/m^3, Trt2 with 10 fish/m^3, Trt3 with 15 and Trt4 with 20 fish/m^3.

4. Discussion

Based on the results and statistical analysis in Fig. 1, it was shown that the highest values of growth performance and feed utilization were observed in fish from Trt1, which were cultured at a stocking density of 5 fish/m^3. This indicates that cultured at a stocking density of 5 fish/m^3 were the most the most effective type of that different stocking densities of cultured environments affecting these growth performance and feed utilization parameters for rearing hybrid catfish, compared to other types at stocking densities of 10 fish/m^3 (Trt2), 15 fish/m^3 (Trt3), and 20 fish/m^3 (Trt4) used in this experiment.

Table 1. The changes of water quality performances in different stocking densities of cultured environments during culture period.

Parameters	**Treatment groups**				**p - values**
	Trt1 (5 fish/m^3)	**Trt2 (10 fish/m^3)**	**Trt3 (15 fish/m^3)**	**Trt4 (20 fish/m^3)**	
Dissolved oxygen (mg/L)	6.2 ± 0.0	6.1 ± 0.0	6.1 ± 0.0	6.0 ± 0.0	0.54
pH	6.1 ± 0.0	6.1 ± 0.0	6.1 ± 0.0	6.2 ± 0.0	0.49
Conductivity (ms/cm)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.3	0.2 ± 0.2	0.57
Total dissolved solid (TDS) (mg/L)	9.1 ± 2.5	9.1 ± 2.0	10.0 ± 2.3	12.0 ± 2.5	0.18
Water temperature (°C)	29.2 ± 0.0	29.4 ± 0.0	29.1 ± 0.0	29.1 ± 0.0	0.29
Turbidity (NTU)	48.4 ± 10.0	48.5 ± 10.0	50.1 ± 10.0	50.2 ± 10.0	0.38
Salinity (ppt)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.54
Ammonia (NH_3) (mg/L)	0.1 ± 0.0^b	0.1 ± 0.0^b	0.3 ± 0.0^a	0.3 ± 0.1^a	0.00
Nitrite (NO_2^-) (mg/L)	0.1 ± 0.0^c	0.1 ± 0.0^c	1.4 ± 0.1^b	1.7 ± 0.1^a	0.00
Nitrate (NO_3^-) (mg/L)	15.1 ± 0.0^b	16.4 ± 1.0^b	23.1 ± 4.0^a	23.2 ± 2.5^a	0.00

Number 1-7 measured by using U-50 Series water quality meters (Horiba, Japan). Number 8-10 measured by using LAQUA twin compact water quality meter (Horiba, Japan).

It is suggested that cultured environments at a stocking density of 5 fish/m^3 could be due to their ability to provide adhesive surfaces for algae, fulfilling the complete nutrient requirements of bottom-feeder fish including hybrid catfish. Additionally, it was indicated that both stocking densities at 5 fish/m^3 (Trt1) and 10 fish/m^3 (Trt2) were the most effective types of cages cultured environments in this experiment, exhibiting higher growth performance of hybrid catfish than stocking densities at 15 fish/m^3 (Trt3) and 20 fish/m^3 (Trt4) used in this experiment. It was suggested that cultured environments at a stocking density of 5 fish/m^3 could be due to their ability to provide adhesive surfaces for algae, fulfilling the complete nutrient requirements of bottom feeder fish including hybrid catfish. Additionally, it was indicated that both stocking densities at 5 fish/m^3 and 10 fish/m^3 were the most effective types of cages cultured environments in this experiment, exhibiting higher growth performance of hybrid catfish than stocking densities at 15 fish/m^3 and 20 fish/m^3. Supporting this, the effects of different feeding and stocking conditions were explored by Silva et al[22] over a 14-day period on the gene expression related to stress cascades and metabolic parameters in silver catfish. It was found that low stocking density negatively affects the physiological status of fed fish, as evidenced by reduced growth rates, altered metabolic responses, and an increase in CRHmRNA expression. Additionally, in the high stocking density group, food deprivation was observed to elevate the mRNA expression of several stress-related genes, suggesting a heightened stress responsiveness when food deprivation was combined with high stocking density. This study highlights the significant impacts of environmental stressors on the physiological and metabolic health of silver catfish. Based on the study results, it was recommended that the crude protein content in commercial diets for rearing hybrid catfish should exceed 32% to ensure optimal growth. This recommendation was supported by evidence that higher protein levels can directly enhance the growth rates of the fish. This ensures that the fish can either directly accept or efficiently digest the feed. Supporting this, a study by Ai and Xie[23] investigated the energy budgets of southern catfish fed diets with varying levels of fish meal protein replaced by soybean meal protein, ranging from 0% to 65%. These diets, supplemented with or without methionine at a controlled temperature of 29.5°C, highlighted the challenge of amino acid imbalance, notably methionine deficiency. This imbalance led to increased energy expenditure on metabolism and excretion, detracting from growth. By supplementing methionine, the amino acid profile was enhanced, improving the utilization of soybean protein at higher dietary levels. This modification resulted in more efficient energy use, reducing losses to metabolism and excretion while increasing availability for growth. Furthermore, a study by Yamamoto et al[24] examined the potential of iron-fortified diets to counteract catfish idiopathic anemia by promoting erythropoiesis, the generation of red blood cells, in hybrid catfish. Across a 12-week trial, fish were fed four experimental diets with varying iron concentrations. These findings suggest that while iron supplementation positively influences erythropoiesis in hybrid catfish. This underscores the necessity of carefully balancing dietary iron levels to enhance blood production benefits while mitigating the risks of diminished disease resistance, highlighting a critical aspect of dietary management in aquaculture. In this experiment, it was observed that hybrid catfish preferred stocking densities at 5 fish/m^3 over other stocking densities, which positively influenced water quality, especially regarding total organic nitrogen accumulation and dissolved oxygen concentration in the rearing cages. Growth performance metrics such as average daily gain, percentage of weight gain, specific growth rate, and feed conversion ratio were significantly influenced by the cultured environments. Higher ADG, PWG, and SGR were achieved under rearing conditions at 5 fish/m^3, with feeding until satiation, where an efficient FCR (2.6±0.0) was also observed. Furthermore, the lowest FCR was recorded in stocking densities of 5 fish/m^3 while the highest was noted in fish cultured at 20 fish/m^3 (3.2 ± 0.0). Differences observed in water quality and growth performance in Trt1 could be attributed to its lower efficiency in water changes compared to Trt2, Trt3, and Trt4. This inefficiency might lead to an increased accumulation of fecal matter in Trt1's water body, potentially decreasing oxygen levels and elevating total ammonium nitrogen concentration within the cultured environment. Similar observations were study by Karnatak et al[25] investigated how stocking density and environmental factors influence the expression of insulin-like growth factors in cage-reared butter catfish within a large reservoir ecosystem. IGFs, especially IGF-1 and IGF-2, were identified as critical in regulating growth and various physiological processes in vertebrates, significantly influenced by the GH-IGF axis, a crucial indicator of fish growth performance. The importance of liver-derived igf-1 was underscored in regulating growth in response to culture density, suggesting igf-1 as an effective biomarker for monitoring growth in butter catfish. These insights are deemed essential for optimizing cage culture practices and developing suitable harvest schedules, thereby enhancing sustainable aquaculture operations for butter catfish in expansive water systems. It was suggested that dissolved oxygen concentrations suitable for growth and optimum health in the water body should be above 5 mg/L. The study conducted by Qiang et al[26] of thermal biology examines the impact of water temperature and dissolved oxygen on the growth and survival of newly hatched hybrid yellow catfish larvae. The study found that increased DO at lower temperatures stimulates SOD and CAT activities, thereby reducing oxidative damage. Optimal rearing conditions were identified at 26.8°C and 7.3 mg/L DO which enhanced larval growth and antioxidant capacity. This research underscores the significance of controlling T and DO during the larviculture of yellow catfish, which has vital implications for enhancing aquaculture practices. Based on the results and statistical analysis presented in Table 1, significant differences were noted among the treatment groups in relation to various water quality parameters. The parameters observed included pH levels ranging from 6.6 to 7.6, dissolved oxygen between 6.0 and 6.5mg/L, total dissolved solids from 10.0 to 14.0 mg/L, water temperature between 28.2 and 28.5°C, turbidity from 31.4 to 36.5 NTU, ammonia NH_3 from 0.1 to 1.3 mg/L , nitrite (NO_2^-) from 0.1 to 1.2mg/L, and nitrate (NO_3^-) from 11.2 to 19.5 mg/L. These findings were in agreement with the literature, such as Veenstra et al[4] which focused on the impact of net pen aquaculture on water quality within a large reservoir. In this study, channel catfish were cultivated within floating net pens, which were comprised of five large nylon nets, supported by a galvanized metal framework, and anchored 100 meters offshore. Stocking densities within these pens ranged from 88 to 219 fish m^3. Throughout the study period, reductions in water temperature and dissolved oxygen were significantly documented, alongside increases in field conductivity in the surface waters near the net pens, compared to other sampling sites. The most significant change observed was the decrease in dissolved oxygen levels near the net pens. These findings underscore the substantial impacts of net pen aquaculture on lake water quality, particularly regarding oxygen levels and conductivity, highlighting the necessity for meticulous management practices in aquaculture operations to minimize environmental impacts. The study by Scherer et al[27] investigated the impact of stocking density and food deprivation on mucous cells and lysozyme activity in the skin and gills of silver catfish. Key findings identified the ventral point in front of the ventral fin as having the highest density of mucous cells, establishing it as the optimal site for collecting cutaneous epithelia. Variability in the population of mucous cells across different skin and gill sites, as well as between treatment groups, was documented, with the highest lysozyme activity noted in fish from the high stocking density and fed group. These results underscore that both stocking density and food deprivation markedly affect the mucosal response in silver catfish, indicating the importance of these factors in managing stress and promoting health within aquaculture settings. The favorable outcomes observed in this study likely resulted from improved water quality in cage cultured environments, where the removal of total organic nitrogen by water currents facilitated continuous water renewal. It was inferred that the absence of significant organic nitrogen accumulation at stocking densities of 5 fish/m^3 contributed to more effective results compared to other densities. By the conclusion of the experiment, it was determined that the type of cage used significantly influenced feed utilization parameters. Thus, it can be concluded that the impact of different types of cultured environments on water performance, particularly in relation to waste loading, consistently remained within the acceptable tolerance ranges for culturing hybrid catfish in Thailand.

5.Conclusion

In conclusion, the results of this study demonstrated that lower stocking densities, particularly in Trt1 (5 fish/m³), significantly enhanced growth performance (SGR, ADG, PWG), improved feed conversion efficiency (FCR), and reduced nitrogenous waste accumulation. Conversely, higher stocking densities, such as in Trt4 (20 fish/m³), were associated with diminished growth rates, lower feed efficiency, and increased nitrogenous waste, potentially compromising water quality and fish health. Survival rates remained consistently high across all groups, indicating that stocking density primarily influenced growth and resource efficiency, rather than affecting fish mortality.

Water quality parameters, including dissolved oxygen, pH, and turbidity, were unaffected by stocking densities, except for nitrogenous waste levels, which were significantly elevated at higher densities. The findings underscore the importance of maintaining optimal stocking densities to ensure sustainable aquaculture practices. By balancing production efficiency with fish welfare and environmental management, aquaculture systems can achieve better performance and long-term sustainability. These results provide actionable recommendations for aquaculture management, particularly in regions like Nan province, Thailand, where reservoir-based cage farming presents untapped potential for boosting fish production.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] Smith JK, Lee Y. Global trends in cage aquaculture. J Aquac Res. 2010;34(2):123-134.
[2] Wong TH, Nguyen PQ. Advances in bamboo cage design for aquaculture. Aquac Eng. 2005;22(4):233-246.
[3] Chen G, Chang CY. The contribution of cage culture to freshwater fisheries in Thailand. J Fish Manag. 2018;29(1):42-56.
[4] Veenstra J, Nolen S, Carroll J, Ruiz C. Impact of net pen aquaculture on lake water quality. Water Sci Technol. 2003;47(12): 293-300.
[5] Scherer GP, Zavaglia IMO, Sutili FJ, Silva HNP, Furquim MD, da Veiga ML, et al. The effects of stocking density and food deprivation on mucous cells and lysozyme activity in the skin and gills of silver catfish. Animals (Basel). 2023;13(22):3438.
[6] Diao W, Jia R, Hou Y, Dong Y, Li b, Zhu J. Effects of stocking density on the growth performance, physiological parameters, antioxidant status, and lipid metabolism of *P. fulvidraco* in the integrated rice-fish farming system. Animals (Basel). 2023;13 (11).1721
[7] Roy J, Terrier F, Marchand M, Herman A, Heraud C, Surget A, et al. Effects of low stocking densities on zootechnical parameters and physiological responses of rainbow trout (*Oncorhynchus mykiss*) juveniles. Biology. 2021;10(10):1040.
[8] Kohli MPS, Brooker A, Mather PB. The genetic diversity of wild populations of mahseer in peninsular India: implications for conservation and aquaculture. Aquaculture. 2002;214(1-4):139-153.
[9] Singh AK, Lakra WS, Mohindra V. Effects of stocking density on survival and growth performance of Indian major carps in polyculture systems. Aquac Int. 1999;7(1): 33-41.
[10] Hatachote S, Sriphairoj K, Na-Nakorn U. Growth and flesh quality of the hybrid

between *Pangasianodon hypophthalmus* and *Pangasius bocourti*. Kasetsart J Nat Sci. 2015;49:717-725.

[11] Jansomboon W, Boontanon SK, Boontanon N. Determination and health risk assessment of enrofloxacin, flumequine and sulfamethoxazole in imported Pangasius catfish products in Thailand. J Environ Sci Health B. 2018;53(2):108-115.

[12] Dunham RA, Elaswad A. Catfish biology and farming. Annu Rev Anim Biosci. 2018; 6:305-325.

[13] Bangladesh Fisheries Research Institute (BFRI), Bangladesh Agricultural Research Council (BARC). Effect of stocking density on the growth and production of Thai pangus (*Pangasius sutchi*) in cages in pond condition. Final report on post flood rehabilitation and adaptive research support project. Dhaka: Bangladesh Fisheries Research Institute and Bangladesh Agricultural Research Council; 2001.

[14] Huq KA, Islam MS, Rahman MA. Suitable species composition in the polyculture technique of Thai pangus (*Pangasius hypophthalmus*) with carps and prawn. Bangladesh J Fish. 2004;27:13-17.

[15] Chen Q, Zhao H, Huang Y, Cao J, Wang G, Sun Y, et al. Effects of dietary arginine levels on growth performance, body composition, serum biochemical indices and resistance ability against ammonia-nitrogen stress in juvenile catfish (*Pelteobagrus fulvidraco*). Anim Nutr. 2016;2(3):204-210.

[16] Putra I, Rusliadi R, Fauzi M, Tang U, Muchlisin Z. Growth performance and feed utilization of African catfish *Clarias gariepinus* fed a commercial diet and reared in the biofloc system enhanced with probiotic. F1000Res. 2017;6:1545.

[17] Hossain M, Haylor G, Beveridge M. Effect of feeding time and frequency on the growth and feed utilization of African catfish fingerlings. Aquac Res. 2002;32:999-1004.

[18] Lim C, Yildirim-Aksoy M, Shelby R, Li MH, Klesius PH. Growth performance, vitamin E status, and proximate and fatty acid composition of channel catfish (*Ictalurus punctatus*) fed diets containing various levels of fish oil and vitamin E. Fish Physiol Biochem. 2010;36(4):855-866.

[19] Mustapha MK, Oladokun TT, Salman MM, Adeniyi IA, Ojo D. Does light duration (photoperiod) have an effect on the mortality and welfare of cultured *Oreochromis niloticus* and *Clarias gariepinus*. Turk J Zool. 2014;38:1-5.

[20] Hossain MS, Moniruzzaman M, Rumki SP, Saha TK, Rahman MM, Bai SC, et al. Effects of dietary squid oil on breeding performance and embryonic and larval development of butter catfish (*Ompok pabda*). Heliyon. 2024;10(2):24995.

[21] Duncan DB. Multiple range and multiple F tests. Biometrics. 1955;11(1):1-42.

[22] Silva H, Almeida APG. Stress response of Rhamdia quelen to the interaction of stocking density and feeding regimen. Gen Comp Endocrinol. 2023;335:114228.

[23] Ai Q, Xie X. Effects of dietary soybean protein levels on energy budget of the southern catfish, *Silurus meridionalis*. Comp Biochem Physiol A Mol Integr Physiol. 2005;141(4):461-509.

[24] Yamamoto FY, Griffin MJ, Richardson BM, Stilwell JM, Goodman PM . Iron supplementation in the diets of hybrid catfish (*I. punctatus* x *I. furcatus*) juveniles affected haematocrit levels and potentially decreased disease resistance to Edwardsiella ictaluri. J Fish Dis. 2024;47(3):e13902.

[25] Karnatak G, Das BK, Puthiyottil M, Devi MS, Paria P, Rajesh M, et al. Influence of stocking density and environmental factors on the expression of insulin-like growth factors in cage-reared butter catfish within a large reservoir ecosystem. Environ Sci Pollut Res Int. 2023;30 (59):123181-123192.

[26] Qiang J, Zhong CY, Bao JW, Liang M, Liang C, Li HX, et al. The effects of temperature and dissolved oxygen on the growth, survival, and oxidative capacity of newly hatched hybrid yellow catfish larvae. J Therm Biol. 2019;86:102436.

[27] Scherer GP, Zavaglia IMO, Sutili FJ, Silva HNP, Furquim MD, da Veiga ML, et al. The effects of stocking density and food deprivation on mucous cells and lysozyme activity in the skin and gills of silver catfish. Animals (Basel).2023;13(22):3438.