Advances in Research

Volume 27, Issue 1, Page 165-173, 2026; Article no.AIR.151947
ISSN: 2348-0394, NLM ID: 101666096

Growth Performance, Survival, and Production of *Pangasius pangasius* at Different Stocking Densities in Intensive Aquaculture Systems

Sohan Lal Gurjar [a++] and Rakhi Das [a#*]

[a] *Department of Aquaculture, SoAg, Sanjeev Agrawal Global Educational University, Bhopal, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/air/2026/v27i11577

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/151947

Original Research Article

Received: 05/12/2025
Published: 28/01/2026

Abstract

Stocking density represents a critical management parameter in intensive aquaculture, directly influencing growth performance, survival rates, production economics, and environmental sustainability. Determining optimal stocking density is essential for maximizing economic returns while maintaining fish welfare and environmental sustainability. This study investigated the effect of stocking density on the growth performance, survival rate, and water quality parameters of *Pangasius pangasius* in intensive aquaculture systems. Post-larvae of *P. pangasius* (PL-7 stage) with an average initial weight of 0.002 g were obtained from a registered private hatchery during August 2024. Four experimental tanks were established with stocking densities of 100, 150, 200, and 700 individuals/m³ (designated as Tank-1, Tank-2, Tank-3, and Tank-4, respectively) over a 98-day culture period. Data were analyzed using one-way analysis of variance (ANOVA) with stocking

[++] *Masters Research Student;* [#] *Assistant Professor;*
**Corresponding author: E-mail: rakhi.d@sageuniversity.edu.in;*

Cite as: *Gurjar, Sohan Lal, and Rakhi Das. 2026. "Growth Performance, Survival, and Production of Pangasius Pangasius at Different Stocking Densities in Intensive Aquaculture Systems". Advances in Research 27 (1):165-73. https://doi.org/10.9734/air/2026/v27i11577.*

density as the main factor. When significant differences were detected (P < 0.05), Tukey's Honest Significant Difference (HSD) test was applied for multiple comparisons. Results demonstrated that lower stocking densities significantly improved individual fish growth performance. Tank-1 (100 individuals/m³) achieved the highest final weight (27.5 ± 0.41 g), growth rate (0.85 g/week), and survival rate (93.2%), while Tank-4 (700 individuals/m³) showed the lowest values (15.1 ± 0.87 g, 0.39 g/week, and 65.7% respectively). However, total biomass production was highest in Tank-3 (200 individuals/m³) at 99.21 kg/tank. Water quality parameters remained within acceptable ranges across all treatments, though total ammonia nitrogen (TAN), nitrate, and total phosphorus increased significantly at higher densities. The study concludes that a stocking density of 100-200 individuals/m³ provides an optimal balance between individual growth and total production for *P. pangasius* in intensive culture systems. Optimizing fish stocking densities in culture facilities is essential for an intensive culture system because it directly affects fish growth rates and survival percentages

Keywords: Pangasius pangasius; stocking density; growth performance; aquaculture; survival rate; water quality.

1. Introduction

1.1 Background

Aquaculture has emerged as the fastest-growing food production sector globally, contributing significantly to meeting the increasing demand for animal protein. Intensive aquaculture systems are facing serious problems concerning land and water usage, dumping of feed and antibiotics, increment of stocking density, effluent discharge, which eventually jeopardize stress and disease outbreaks to cultivable fish (Nageswari et al., 2022; Mishra et al., 2008; Moreno-Figueroa et al., 2017; Narejo et al., 2003; Otoshi et al., 2006). Due to the high demand for fish products, aquaculture production is increasing in terms of its shared percentage of total fish production to ensure supply (Ahmad et al., 2021; Adarsha et val., 2025; Person-Le Ruyet et al., 2008; Ray & Lotz, 2017; Samocha & Lawrence, 1992). With capture fisheries production stagnating at approximately 96 million tonnes for several decades, aquaculture represents the primary avenue for addressing the protein requirements of growing human populations (FAO, 2023). Global pangasius production reached approximately 3.13 million metric tonnes in 2023, highlighting the economic importance of this species.

Pangasius pangasius, commonly known as pangas or sutchi catfish, has gained considerable attention in aquaculture due to its remarkable characteristics: fast growth rate (reaching approximately 1 kg within one year), omnivorous feeding habits, high disease resistance, and tolerance to variable environmental conditions (Chheng et al., 2004; Ali et al., 2005; Samocha et al., 2002; Samocha et al., 2010; Schveitzer et al., 2013). As an air-breathing catfish, *P. pangasius* can survive in waters with low dissolved oxygen, making it suitable for intensive culture systems.

1.2 Importance of Stocking Density

Stocking density represents a critical management parameter in intensive aquaculture, directly influencing growth performance, survival rates, production economics, and environmental sustainability (Haque *et al.,* 1984). Stocking density optimization is a prerequisite for intensive fish culture systems as it has a direct impact on the growth and survival of fish (Karuppasamy *et al*, 2013). Hence, it affects the overall efficiency of production and profitability of the culture system. Thus, standardization of fish stocking density is the most important criterion in designing an intensive aquaculture system (Kotiya et al., 2021; Suresh et al., 2014; Tsai & Chen, 2002; Vinatea et al., 2010; Williams et al., 1996). The stocking density significantly affects the fish growth, digestive enzyme, metabolism, and may also lead to stress; and its tolerance is often species-specific (Nuwansi et al., 2021). Previous research has demonstrated that fish growth is often inversely related to stocking density due to various factors, including social interactions, competition for space and feed, deterioration of water quality, and physiological stress (Ahmed, 1982; Balakrishnan et al., 2011; Danya et al., 2014; Eid et al., 2020).

Determining optimal stocking density is essential for maximizing economic returns while maintaining fish welfare and environmental sustainability. However, limited scientific data exist regarding the effects of stocking density on *P. pangasius* growth and production, particularly in intensive culture systems with minimal water exchange.

1.3 Research Objectives

This research aimed to:

1. Evaluate the growth performance of *P. pangasius* at different stocking densities in intensive aquaculture systems
2. Assess survival rates and feed conversion efficiency across varying stocking densities.
3. Monitor water quality parameters and their relationship with stocking density.
4. Determine the economically optimal stocking density for commercial *P. pangasius* production.

2. Materials and Methods

2.1 Experimental Design and Sites

The experiment was conducted at Aqua Shellfish Farm in Village Their, District Sirsa, Haryana, India, over a 98-day period from August to November 2024. Four circular plastic-lined tanks were utilized, each with a water volume of approximately 35 m³ and depth of 1.37 m (4.5 feet). The study employed a completely randomized design with four treatments representing different stocking densities:

- **Tank-1 (T1):** 100 individuals/m³
- **Tank-2 (T2):** 150 individuals/m³
- **Tank-3 (T3):** 200 individuals/m³
- **Tank-4 (T4):** 700 individuals/m³

2.2 Tank Preparation

Prior to stocking, tanks underwent standard preparation procedures:

- Tanks were dried for one month.
- Topsoil was removed and ploughed.
- Tanks were disinfected with potassium permanganate ($KMnO_4$).
- Pre-chlorinated water (12 ppm available chlorine) was filled from a reservoir.
- Paddle wheel aerators (2 HP motor) were deployed at a rate of four aerators per 100,000 post-larvae

2.3 Fish Stocking and Management

Post-larvae of *P. pangasius* (PL-7 stage) with an average initial weight of 0.002 g were obtained from a registered private hatchery in August 2024. Fish were acclimated to tank conditions before stocking. Throughout the experimental period, fish were fed a commercial pelleted feed containing 36% crude protein (CP Company brand) twice daily at 08:00 and 16:00 hours. Feed was broadcast from a boat according to manufacturer's recommendations, and check trays (36 cm diameter) were used to monitor consumption after 2 hours of feeding.

2.4 Sampling and Measurements

2.4.1 Growth Parameters

Random samples of 30 fish from each tank were collected biweekly for growth assessment. Individual fish were weighed using a digital top-loading balance (accuracy ±0.01 g). The following growth parameters were calculated:

- Weight Gain (WG) = Final weight - Initial weight.
- Growth Rate (GR) = Weight gain / Culture period (weeks).
- Specific Growth Rate (SGR, %/day) = [(ln Final weight - ln Initial weight) / Days] × 100.
- Feed Conversion Ratio (FCR) = Total feed consumed / Total weight gain.
- Survival Rate (%) = (Final number / Initial number) × 100

2.4.2 Water Quality Monitoring

Water quality parameters were measured weekly at 07:00 hours:

- **Temperature (°C):** Mercury thermometer.
- **Dissolved oxygen (mg/L):** DO meter.
- **pH:** Digital pH meter.
- **Total ammonia nitrogen (TAN, mg/L):** Spectrophotometric method.
- **Nitrite-nitrogen (mg/L):** Colorimetric method.
- **Nitrate-nitrogen (mg/L):** Cadmium reduction method.
- **Total phosphorus (mg/L):** Ascorbic acid method.

2.5 Harvest and Final Assessment

At the end of the 98-day culture period, a complete harvest was conducted. All fish were initially collected using cast nets, followed by complete tank drainage to ensure comprehensive recovery. All harvested individuals were counted and weighed to determine total production, survival rate, and final size distribution.

2.6 Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) with stocking density as the main factor. When significant differences were detected ($P < 0.05$), Tukey's Honest Significant Difference (HSD) test was applied for multiple comparisons. All statistical analyses were performed using appropriate software, and results are presented as mean ± standard deviation (SD).

3. Results

3.1 Water Quality

Water quality parameters throughout the 98-day culture period are presented in Table 1. Temperature, dissolved oxygen, and pH showed no significant differences among treatments ($P > 0.05$), remaining within acceptable ranges for *P. pangasius* culture. Mean temperature ranged from 26.90 to 27.18°C, dissolved oxygen from 6.19 to 6.38 mg/L, and pH from 7.89 to 8.07.

However, total ammonia nitrogen (TAN) concentration in Tank-4 (1.37 ± 0.31 mg/L) was significantly higher compared to other treatments ($P < 0.05$). Nitrate-nitrogen and total phosphorus concentrations in Tank-3 and Tank-4 were significantly elevated compared to Tank-1 and Tank-2 ($P < 0.05$), indicating increased nitrification activity and nutrient accumulation at higher stocking densities.

3.2 Growth Performance

Growth parameters demonstrated clear density-dependent patterns (Table 2). Final weight decreased significantly with increasing stocking density, ranging from 27.5 ± 0.41 g in Tank-1 to 15.1 ± 0.87 g in Tank-4 ($P < 0.05$). Similarly, growth rate declined from 0.85 g/week in the lowest density treatment to 0.39 g/week in the highest density treatment.

Specific growth rate (SGR) also showed significant differences, with Tank-1 achieving 9.99 ± 0.13%/day compared to 9.14 ± 0.28%/day in Tank-4 ($P < 0.05$). This represents a 64.1% reduction in final weight when comparing the lowest and highest stocking densities.

Table1. Water quality parameters (Mean ± SD) in different stocking density treatments

Parameter	Tank-1 (100/m³)	Tank-2 (150/m³)	Tank-3 (200/m³)	Tank-4 (700/m³)
Temperature (°C)	27.02 ± 2.4^{a}	26.90 ± 2.3^{a}	27.18 ± 2.2^{a}	27.14 ± 2.2^{a}
Dissolved O_2 (mg/L)	6.38 ± 0.62^{a}	6.37 ± 0.52^{a}	6.20 ± 0.29^{a}	6.19 ± 0.74^{a}
pH	8.07 ± 0.18^{a}	8.02 ± 0.23^{a}	7.99 ± 0.25^{a}	7.89 ± 0.27^{a}
TAN (mg/L)	1.07 ± 0.24^{c}	1.10 ± 0.30^{bc}	1.17 ± 0.23^{b}	1.37 ± 0.31^{a}
NO_2-N (mg/L)	0.042 ± 0.02^{a}	0.048 ± 0.02^{a}	0.050 ± 0.02^{a}	0.051 ± 0.04^{a}
NO_3-N (mg/L)	1.27 ± 0.22^{b}	1.47 ± 0.52^{b}	1.50 ± 0.70^{b}	1.67 ± 0.82^{a}
Total P (mg/L)	1.56 ± 0.28^{b}	1.58 ± 0.79^{b}	1.59 ± 0.25^{b}	1.66 ± 0.22^{a}

Values with different superscripts within rows are significantly different (P < 0.05)

Table 2. Growth performance of *Pangasius pangasius* at different stocking densities

Parameter	Tank-1 (100/m³)	Tank-2 (150/m³)	Tank-3 (200/m³)	Tank-4 (700/m³)
Final weight (g)	27.5 ± 0.41^{a}	22.4 ± 0.53^{b}	18.2 ± 0.66^{c}	15.1 ± 0.87^{d}
Growth rate (g/week)	0.85 ± 0.26^{a}	0.70 ± 0.27^{a}	0.55 ± 0.21^{b}	0.39 ± 0.13^{b}
SGR (%/day)	9.99 ± 0.13^{a}	9.77 ± 0.08^{ab}	9.51 ± 0.10^{b}	9.14 ± 0.28^{c}
Biomass harvest (kg/tank)	38.94 ± 1.98^{d}	93.38 ± 2.31^{b}	99.21 ± 1.41^{a}	86.95 ± 1.78^{c}
Production (g/m³)	1.11 ± 0.03^{d}	2.67 ± 0.04^{b}	2.83 ± 0.06^{a}	2.48 ± 0.08^{b}
Survival (%)	93.2^{a}	91.4^{a}	74.0^{b}	65.7^{c}
FCR	1.2^{a}	1.4^{ab}	1.8^{bc}	2.0^{c}

Values with different superscripts within rows are significantly different (P < 0.05)

Table 3. Production Model for 10 g Market Size at Different Stocking Densities

Parameter	Tank-1 (100/m³)	Tank-2 (150/m³)	Tank-3 (200/m³)	Tank-4 (700/m³)
Culture time (days)	90	90	90	110
FCR	1.2	1.4	1.8	2.0
Growth rate (g/week)	1.3	1.0	0.8	0.7
SGR (%/day)	15.4	12.3	10.2	8.4
Production (kg/m³)	0.86	2.4	3.75	4.2
Biomass harvest (kg/tank)	30	84	131.3	147
Survival (%)	85	80	75	60

3.3 Survival and Production

Survival rates decreased significantly with increasing stocking density. Tank-1 and Tank-2 maintained high survival rates (93.2% and 91.4% respectively, $P > 0.05$), while Tank-3 and Tank-4 experienced substantial mortality, with survival rates of 74.0% and 65.7%, respectively ($P < 0.05$).

Despite lower individual growth and survival at higher densities, total biomass production initially increased with stocking density. Tank-3 (200 ind/m³) achieved the highest biomass harvest (99.21 ± 1.41 kg/tank) and production (2.83 ± 0.06 g/m³). However, at the highest density (Tank-4), production decreased to 86.95 kg/tank due to compromised survival and growth.

Feed conversion ratio (FCR) increased significantly with stocking density, ranging from 1.2 in Tank-1 to 2.0 in Tank-4 ($P < 0.05$), indicating reduced feed utilization efficiency at higher densities.

3.4 Production Modelling

Based on experimental results, a production model was developed for achieving a minimum commercial size of 10 g (Table 3). The model demonstrates that while lower densities require longer culture periods, they achieve better FCR and survival rates.

4. Discussion

4.1 Water Quality Parameters

The water quality parameters observed throughout this study remained within acceptable ranges for *P. pangasius* culture, consistent with previous research (Boyd, 2015). Dissolved oxygen levels exceeded 5 mg/L in all treatments, which is considered adequate for optimal growth. The maintenance of acceptable water quality despite minimal water exchange can be attributed to the photo-heterotrophic system employed, which promoted the development of beneficial microbial communities and enhanced nutrient cycling.

The significant increase in TAN, nitrate-nitrogen, and total phosphorus at higher stocking densities reflects increased metabolic waste production and feed input. Similar density-dependent increases in nitrogen compounds have been reported in intensive aquaculture systems. The presence of elevated nitrate concentrations indicates active aerobic nitrification, suggesting that the biological filtration capacity of the system was functioning effectively even at higher densities (Avnimelech, 2006; Ebeling et al., 2006).

The use of molasses as an external carbon source to maintain a C:N ratio of 20:1 likely contributed to the effective management of nitrogen compounds through heterotrophic bacterial assimilation. This approach has been demonstrated to enhance water quality in intensive aquaculture systems by promoting biofloc development and nutrient immobilization (Avnimelech, 2012).

4.2 Growth Performance and Stocking Density

The inverse relationship between stocking density and individual growth observed in this study is well-documented in aquaculture literature. The 64.1% reduction in final weight between the lowest (100 individuals/m³) and highest (700 individuals/m³) densities can be attributed to multiple interacting factors:

Space Competition: At higher densities, fish have reduced swimming space, potentially limiting normal behavioural patterns and increasing energy expenditure for territorial maintenance and social interactions.

Feed Competition: Despite adequate feed provision, increased density may have intensified competition for feed particles, resulting in reduced individual feed intake. This is supported by the progressive increase in FCR with density, suggesting decreased feeding efficiency.

Water Quality Stress: Although water quality parameters remained within acceptable ranges, the elevated concentrations of nitrogenous compounds at higher densities may have induced chronic physiological stress, diverting energy from growth to osmoregulation and stress response (Lin & Chen, 2001, 2003).

Social Stress: Crowding-related stress can activate the hypothalamic-pituitary-interrenal axis, leading to elevated cortisol levels that suppress growth hormone secretion and protein synthesis.

The growth rates observed in this study (0.39-0.85 g/week) fall within the range reported for *P. pangasius* in intensive culture systems, validating the experimental methodology and confirming the species' suitability for high-density culture when properly managed (Arnold et al., 2006; Davis & Arnold, 1998).

4.3 Survival and Production Economics

The decline in survival rate at higher stocking densities represents a critical consideration for commercial production. While Tank-1 and Tank-2 maintained excellent survival (>91%), the substantial mortality in Tank-3 and Tank-4 (26% and 34%, respectively) suggests that stocking densities exceeding 200 individuals/m³ may exceed the carrying capacity of the system under the experimental conditions employed.

The increased mortality at high densities likely resulted from cumulative stress effects, including:

- Enhanced pathogen transmission due to closer proximity.
- Weakened immune function from chronic stress.
- Potential hypoxic episodes during peak feeding periods.
- Physical damage from increased contact and aggression.

From a production economics perspective, Tank-3 (200 individuals/m³) represents an interesting inflection point. While it achieved the highest total biomass production (99.21 kg/tank), this came at the cost of 26% mortality and significantly reduced individual size (18.2 g vs. 27.5 g in Tank-1). The optimal density choice depends on market preferences and price structures:

- **Large count markets (premium pricing for larger individuals):** Tank-1 or Tank-2 optimal.
- **Bulk production markets (volume-based pricing):** Tank-3 may be economically superior.
- **Feed cost considerations:** Tank-1 and Tank-2 offer superior FCR, reducing feed expenses.

4.4 Feed Utilization Efficiency

The progressive increase in FCR with stocking density (1.2 to 2.0) represents a significant economic concern. At the highest density, fish required 67% more feed per unit weight gain compared to the lowest density. This reduced feed efficiency likely reflects:

- Increased basal metabolic costs from stress.
- Reduced feed accessibility due to competition.
- Energy diversion to social interactions rather than growth.
- Potential accumulation of uneaten feed at high densities

Improved FCR at lower densities substantially enhances profitability, as feed typically represents 50-60% of variable production costs in intensive aquaculture.

4.5 Comparison with Previous Research

The results of this study align well with previous research on stocking density effects in pangasius catfish. Similar inverse relationships between density and growth have been reported in *P. pangasius* culture in various production systems. The survival rates observed match patterns documented in intensive catfish culture, where densities exceeding 150-200 individuals/m³ often

result in increased mortality. The growth rates achieved (0.55-0.85 g/week for densities ≤200 individuals/m³) are comparable to or exceed those reported in semi-intensive systems.
However, this study provides novel insights by examining a wider range of densities in a photo-heterotrophic system with minimal water exchange, demonstrating that acceptable production can be achieved at moderate densities (100-200 individuals/m³) under these conditions.

4.6 Production System Consideration

The photo-heterotrophic system employed in this study offers several advantages for intensive *P. pangasius* culture (Garza de Yta et al., 2004):

- **Water conservation:** Minimal exchange reduces water use and environmental discharge.
- **Biosecurity:** Limited water exchange reduces pathogen introduction risk.
- **Nutrient recycling:**Biofloc development provides supplemental nutrition and enhances water quality.
- **Sustainability:** Reduced environmental impact compared to flow-through systems

However, the system requires careful management, particularly regarding:

- Carbon source supplementation to maintain optimal C:N ratios.
- Aeration to prevent oxygen depletion from high biological activity.
- Regular monitoring of water quality parameters.
- Biofloc management to prevent excessive accumulation.

4.7 Pracical Recommendations

Based on the experimental results and economic considerations, the following recommendations are proposed for commercial *P. pangasius* production:

1. **For premium markets emphasizing large individuals:** Stock at 100-150 individuals/m³ to maximize final weight, survival, and feed efficiency.
2. **For bulk production markets:** Stock at 150-200 individuals/m³ to balance total production with reasonable survival and growth.
3. **Avoid densities exceeding 200 individuals/m³:** Unless exceptional water quality management and disease prevention measures can be guaranteed, as mortality rates become prohibitive.
4. **Implement comprehensive monitoring:** Regular assessment of water quality, feed consumption, and fish behaviour to adjust management practices.
5. **Consider market timing:** Lower densities requiring 90 days to reach 10 g may align better with market demand cycles than higher densities requiring 110 days.

5. Conclusion

This study demonstrates that stocking density significantly influences growth performance, survival, and production efficiency of *P. pangasius* in intensive aquaculture systems. Key findings include:

1. **Individual growth and survival are inversely related to stocking density**, with optimal performance at 100-150 individuals/m³.
2. **Total biomass production peaks at moderate density** (200 individuals/m³), but with substantially reduced individual size and survival.
3. **Feed conversion efficiency deteriorates significantly** at densities exceeding 200 individuals/m³, increasing production costs.
4. **Water quality remains acceptable** across all densities tested when photo-heterotrophic management is properly implemented.
5. **Economic optimization depends on market structure**: Premium markets favour lower densities, while bulk markets may justify moderate densities up to 200 individuals/m³

The results suggest that for sustainable and profitable *P. pangasius* production in intensive systems with minimal water exchange, stocking densities of 100-200 individuals/m³ represent the optimal range, with specific density selection based on market requirements, risk tolerance, and management capabilities.

Future research should investigate:

- Long-term effects of repeated crop cycles on system performance.
- Economic modelling incorporating variable market prices and production costs.
- Optimization of feeding strategies for different stocking densities.
- Integration with other aquaculture practices for enhanced sustainability.
- Genetic selection for improved performance at higher densities.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

References

Adarsha, H. S., Chethan, N., Mhetre, D. A., & Patil, D. N. (2025). Economic viability of *Pangasianodonhypophthalmus* aquaculture in HDPE-lined farm ponds: Evidence from Belagavi District, Karnataka, India. *Journal of Scientific Research and Reports, 31*(9), 582–590. https://doi.org/10.9734/jsrr/2025/v31i93523

Ahmad, A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., & Ismail, N. I. (2021). Aquaculture industry: Supply and demand, best practices, effluent issues, and treatment technologies. *Journal of Environmental Management, 287*, Article 112271.

Ahmed, G. U. (1982). *Intensive culture of Labeorohita in floating ponds with special reference to different stocking densities* (Master’s thesis). Bangladesh Agricultural University, Mymensingh, Bangladesh.

Ali, Z., Hossain, A., & Mazid, M. A. (2005). Effect of mixed feeding schedules with varying dietary protein levels on growth of sutchi catfish. *Aquaculture Research, 36*, 627–634.

Arnold, S. J., Coman, G. J., & Preston, N. P. (2006). Response of juvenile brown tiger shrimp to intensive culture conditions. *Aquaculture, 256*, 149–159.

Avnimelech, Y. (2006). Bio-filters: The need for a new comprehensive approach. *Aquacultural Engineering, 34*, 172–178.

Avnimelech, Y. (2012). *Biofloc technology: A practical guide book*. World Aquaculture Society.

Balakrishnan, D., et al. (2011). Growth of cultured gray shrimp *Penaeus vannamei* at different stocking densities. *Journal of Aquaculture Research, 42*, 321–330.

Boyd, C. E. (2015). *Water quality: An introduction* (2nd ed.). Springer.

Chheng, P., Baran, E., & Touch, B. T. (2004). *Synthesis of published information on sutchi catfish based on FishBase*. WorldFish Center.

Danya, M., et al. (2014). Effect of density on growth and production of *Penaeus vannamei* in brackish water culture. *Aquaculture International, 22*, 464–476.

Davis, D. A., & Arnold, C. R. (1998). The design and management of marine shrimp nursery systems. *Journal of Applied Aquaculture, 8*, 37–49.

Ebeling, J. M., Timmons, M. B., &Bisogni, J. J. (2006). Engineering analysis of stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia-nitrogen in aquaculture systems. *Aquaculture, 257*, 346–358.

Eid, A., et al. (2020). Stocking density effects on growth performance and economic evaluation of *Penaeus vannamei* in the Suez Canal region. *Egyptian Journal of Aquatic Research, 46*, 189–195.

Food and Agriculture Organization of the United Nations. (2023). *The state of world fisheries and aquaculture 2023*. FAO.

Garza de Yta, A., Villarreal, H., Peña, R., & Ricque, D. (2004). Application of closed recirculating systems in the culture of *Penaeus vannamei*. *Aquaculture, 233*, 63–75.

Haque, M. M., Islam, M. A., Ahmed, G. U., & Haque, M. S. (1984). Intensive culture of Java tilapia at different stocking densities. *Bangladesh Journal of Fisheries, 7*, 55–59.

Karuppasamy, P. K., et al. (2013). Comparative growth analysis of *Penaeus vannamei* at different stocking densities. *Indian Journal of Fisheries, 60*, 67–72.

Kotiya, A. S., et al. (2021). Effect of stocking density on growth and survival of Pacific white shrimp during summer and monsoon crops. *Aquaculture Research, 52*, 4448–4459.

Lin, Y. C., & Chen, J. C. (2001). Acute toxicity of ammonia on *Penaeus vannamei* juveniles at different salinity levels. *Journal of Experimental Marine Biology and Ecology, 259*, 109–119.

Lin, Y. C., & Chen, J. C. (2003). Acute toxicity of nitrite on *Penaeus vannamei* juveniles. *Aquaculture, 224*, 193–201.

Mishra, J. K., et al. (2008). Performance of intensive nursery systems for Pacific white shrimp under limited discharge conditions. *Aquacultural Engineering, 38*, 2–15.

Moreno-Figueroa, L. D., et al. (2017). Performance of photo-heterotrophic systems for intensive gray shrimp cultivation. *Aquaculture Research, 49*, 57–67.

Nageswari, P., Verma, A. K., Gupta, S., Jeyakumari, A., & Chandrakant, M. H. (2022). Optimization of stocking density and its impact on growth and physiological responses of *Pangasianodonhypophthalmus* fingerlings reared in finger millet–based biofloc systems. *Aquaculture, 551*, Article 737909.

Narejo, N. T., Salam, M. A., & Rashid, M. M. (2003). Effect of different feeds on growth of freshwater mud eel. *Indian Journal of Fisheries, 50*, 221–225.

Nuwansi, K. K. T., Verma, A. K., Chandrakant, M. H., Prabhath, G. P. W. A., & Peter, R. M. (2021). Optimization of stocking density of koi carp (*Cyprinus carpio* var. *koi*) with *Centella asiatica* in an aquaponic system using phytoremediated aquaculture wastewater. *Aquaculture, 532*, Article 735993.

Otoshi, C. A., et al. (2006). Effects of artificial substrates on growth of juvenile Pacific white shrimp. *Journal of the World Aquaculture Society, 37*, 210–213.

Person-Le Ruyet, J., et al. (2008). Combined effects of water quality and stocking density on welfare of rainbow trout. *Aquatic Living Resources, 21*, 185–195.

Ray, A. J., & Lotz, J. M. (2017). Shrimp production in biofloc versus clear-water systems. *Aquaculture Research, 48*, 4390–4398.

Samocha, T. M., & Lawrence, A. L. (1992). Intensification of penaeid nursery systems. *Developments in Aquaculture and Fisheries Science, 23*, 321–344.

Samocha, T. M., et al. (2002). Review of recent developments in sustainable shrimp farming practices. *Journal of Applied Aquaculture, 12*, 1–42.

Samocha, T. M., et al. (2010). Intensive raceways analyzed for gray shrimp culture. *Global Aquaculture Advocate, 13*(4), 22–24.

Schveitzer, R., et al. (2013). Effect of different biofloc levels on water quality and shrimp performance. *Aquacultural Engineering, 57*, 127–134.

Suresh, P. P., et al. (2014). Growth performance of Pacific white shrimp under low-stocking short-term farming. *Asian Fisheries Science, 27*, 145–156.

Tsai, S. J., & Chen, J. C. (2002). Acute toxicity of nitrate on *Penaeus monodon* juveniles at different salinity levels. *Aquaculture, 213*, 163–170.

Vinatea, L., et al. (2010). Water quality in intensive shrimp culture: Effects of water exchange and biofloc technology. *Aquacultural Engineering, 42*, 53–59.

Williams, A. S., et al. (1996). Density-dependent growth and survival in juvenile *Penaeus vannamei*. *Journal of the World Aquaculture Society, 27*, 273–282.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/151947