Iranian Journal of Fisheries Sciences
http:doi.org/ 10.22092/ijfs.2025.133790 2025, 24(3) 619-631

Research Article

Optimizing shrimp growth and yield production: A comparative study of Pacific white shrimp farms along the Persian Gulf coastline

Sharifinia M.[1*], Dashtiannasab A.[1], Keshavarzifard M.[1], Pazir M.K.[1]

1Shrimp Research Center, Iranian Fisheries Sciences Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Bushehr, Iran
*Correspondence: moslem.sharifinia@yahoo.com; m.sharifinia@areeo.ac.ir

Keywords

Shrimp farming,
Growth and yield optimization,
Stocking density,
Aeration rate,
Sustainable practices

Article info

Received: April 2024
Accepted: December 2024
Published: May 2025

Abstract

This study aimed to compare the growth and yield of shrimp in different farms of the Heleh (H1, H2, and H3) and Shif (S1, S2, and S3) shrimp farming complexes and investigate the correlation between stocking density, aeration rate, automatic feeder usage, culture period, and harvested yield. Statistical analysis was performed to compare means for average daily growth rate, mean body weight, final yield (ton), survival rate (SR %), feed conversion ratio (FCR), and specific growth rate (SGR) across different farms. The results showed significant differences ($p<0.05$) between different farms for the parameters under investigation in the Heleh shrimp farming complex, while for Shif, no significant differences were found between different farms for average daily growth rate, FCR, and SGR ($p>0.05$). However, significant differences ($p<0.05$) were observed in SR (%), mean body weight, and final yield between different farms in Shif. Further analysis using Pearson correlation showed a high correlation (R>0.9) between the production level and the stocking density, aeration rate, and culture period. While the production level increased with an increasing number of automatic feeders, no significant correlation was found between these two parameters. Additionally, a positive correlation was observed between the SR (%) and the stocking density and the number of aerators. These results provide valuable insights into the factors that influence shrimp growth and yield, which can be useful for the development of more efficient and sustainable shrimp farming practices in both Heleh and Shif shrimp farming complexes.

Introduction

Shrimp aquaculture has emerged as a vital sector within the global seafood industry, playing a crucial role in meeting the increasing demand for high-quality protein sources (Sharifinia *et al*., 2023a, 2023b). As one of the fastest-growing segments of aquaculture, shrimp farming not only contributes significantly to food security but also supports the livelihoods of millions of people worldwide (Khanjani and Sharifinia, 2022; Khanjani *et al*., 2024; Sharifinia, 2025). With its economic potential, shrimp aquaculture offers opportunities for rural development, job creation, and export revenue, particularly in coastal regions where traditional fishing practices are declining. However, the sustainability of this industry is paramount, as it faces challenges such as environmental degradation, disease outbreaks, and fluctuating market conditions (Boyd *et al*., 2020; Dey and Sanyal, 2023; N'Souvi *et al*., 2024; Tien Nguyen *et al*., 2024). By optimizing farming practices and implementing innovative management strategies, shrimp aquaculture can continue to thrive, ensuring a balance between productivity and ecological responsibility. This highlights the importance of research and development in enhancing shrimp growth, yield, and overall sustainability within this dynamic industry.

Shrimp farming has become a significant contributor to the seafood industry's global production, with the Pacific white shrimp (*Litopenaeus vannamei*) being the most widely cultured shrimp species worldwide (Khanjani and Sharifinia, 2020; Khanjani *et al*., 2023; Sharifinia, 2024; Sharifinia *et al*., 2024). Iran is among the countries that have made significant progress in shrimp farming in recent years, with the Persian Gulf coastline being a major area of shrimp production. However, the industry is not without its challenges, such as disease outbreaks, environmental deterioration, and economic feasibility (Dhar *et al*., 2020; Tacon and Metian, 2008; Yeganeh *et al*., 2020). In order to overcome these challenges and maintain the sustainability of the industry, it is crucial to implement effective management practices (Lightner, 2021). By doing so, the industry can ensure the availability of high-quality shrimp while minimizing the impact on the environment and achieving economic viability. Therefore, it is essential to identify and implement best practices in shrimp farm management to ensure the long-term success of the industry (Flegel, 2019; Bush *et al*., 2021; Delphino *et al*., 2022).

The yield production of shrimp farms is influenced by various management factors. These factors include aeration systems, auto feeders, biosecurity measures, liners, and stocking density, which can all significantly affect the growth and survival of shrimp in aquaculture systems. It is crucial to properly manage these factors to ensure the achievement of maximum yields and profitability. Several studies have explored the influence of these management factors on shrimp farming. For instance, Lim *et al.* (2021) revealed that the aeration rate had a notable impact on water quality, growth performance, and production of Pacific white shrimp. Aeration rate is a critical factor in shrimp farming, as it affects dissolved oxygen levels, which are essential for shrimp growth and survival (Li *et al*., 2006; Suwoyo *et al*., 2021). Studies have reported a positive correlation between aeration rate and shrimp growth and yield (McGraw *et al*., 2001; Ruiz-Velazco *et al*., 2010). However, excessive aeration can also lead to stress and mortality in shrimp. Therefore, optimal aeration rates need to be determined to ensure maximum shrimp growth and yield.

Espinoza-Ortega *et al*. (2023) and Arambul-Muñoz *et al*. (2019) observed that feeding strategies and stocking densities influenced the survival and growth of Pacific white shrimp. Additionally, Kring *et al*. (2023) demonstrated that stocking density significantly affected the production, growth, and survival of Pacific white shrimp in greenhouse-based biofloc systems. However, high stocking densities can also lead to poor water quality and disease outbreaks, which negatively impact shrimp growth and yield (Anh *et al*., 2022). Therefore, optimal stocking densities need to be determined to ensure maximum shrimp growth and yield. Besides, the use of auto feeders can help maintain consistent feeding rates and reduce labor costs, resulting in improved growth rates and yields (Inayathullah *et al*., 2021).

Biosecurity measures are also critical in preventing the introduction and spread of pathogens in shrimp farms. Proper biosecurity measures, such as disinfection and quarantine, can significantly reduce the risk of disease outbreaks and prevent economic losses (Delphino *et al*., 2022). Moreover, the use of liners in shrimp ponds can also help prevent the loss of water and improve water quality, resulting in improved growth rates and yields (Fleckenstein *et al*., 2020). Stocking density is another important factor that can significantly impact the yield production of shrimp farms. Overstocking can lead to poor water quality, disease outbreaks, and reduced growth rates, while understocking can result in inefficient use of resources and decreased profitability (Westers *et al*., 2017; Araneda *et al*., 2020). Therefore, it is important to maintain optimal stocking densities to ensure maximum yields and profitability.

The aim of this study is to compare the growth and yield of shrimp in different farms of two shrimp farming complexs (Heleh and Shif). We also aim to investigate the correlation between stocking density, aeration rate, automatic feeder usage, culture period, and harvested yield. The results of this study can provide valuable insights into the factors that influence shrimp growth and yield, which can be useful for the development of more efficient and sustainable shrimp farming practices.

Materials and methods

Ecological conditions of study area:

Bushehr Province is situated between 17°27' to 30°10' North latitude and 50°02' to 52°41' East longitude. Recent studies conducted on the Integrated Coastal Zone Management (ICZM) project indicate that the length of the land coasts in Bushehr Province is 870 kilometers, while its islands stretch for 67 kilometers. The entire sea border of Bushehr Province measures 937 kilometers. The average surface water temperature in the Persian Gulf's Bushehr Province area is 26.6˚C. In detail, this indicator averages 28.2˚C in the spring, 33.4˚C in the summer, 24.9˚C in the autumn, and 19.8˚C in the winter. Moreover, the average salinity of the Persian Gulf in the Bushehr Province area is 42 ppt, with averages of 39.7 ppt in the spring, 39.6 ppt in the summer, 40.2 ppt in the autumn, and 40.4 ppt in the winter (Izadpanahi *et al*., 2005). Despite the aforementioned ecological conditions, the cultivation of Pacific white shrimp in the shrimp farms of Bushehr Province occurs in salinity levels exceeding 47 ppt, pH range of 7.8 to 3.7, and temperature ranges of 25 to 38 degrees Celsius. Notably, there are currently nine shrimp farming complexes in the province, consisting of 20-hectare farms, each containing 14 to 20 ponds. The shrimp cultivation period in Bushehr Province takes place once a year, from late April to late November.

Study area

The current study was carried out in two major shrimp farming complexes located in Bushehr Province, namely Shif and Heleh (Fig. 1). For the purpose of this research, three farms were selected from each of the aforementioned complexes, and the various stages of shrimp farming management were meticulously monitored throughout a one cultivation cycle. To this end, both field visits and information obtained from farm managers through questionnaires were employed, in collaboration with the Iran Shrimp Research Center. The field visits were conducted every 14 days across the three shrimp farming complexes in Bushehr Province to ensure a comprehensive and exhaustive analysis of the shrimp farming management practices.

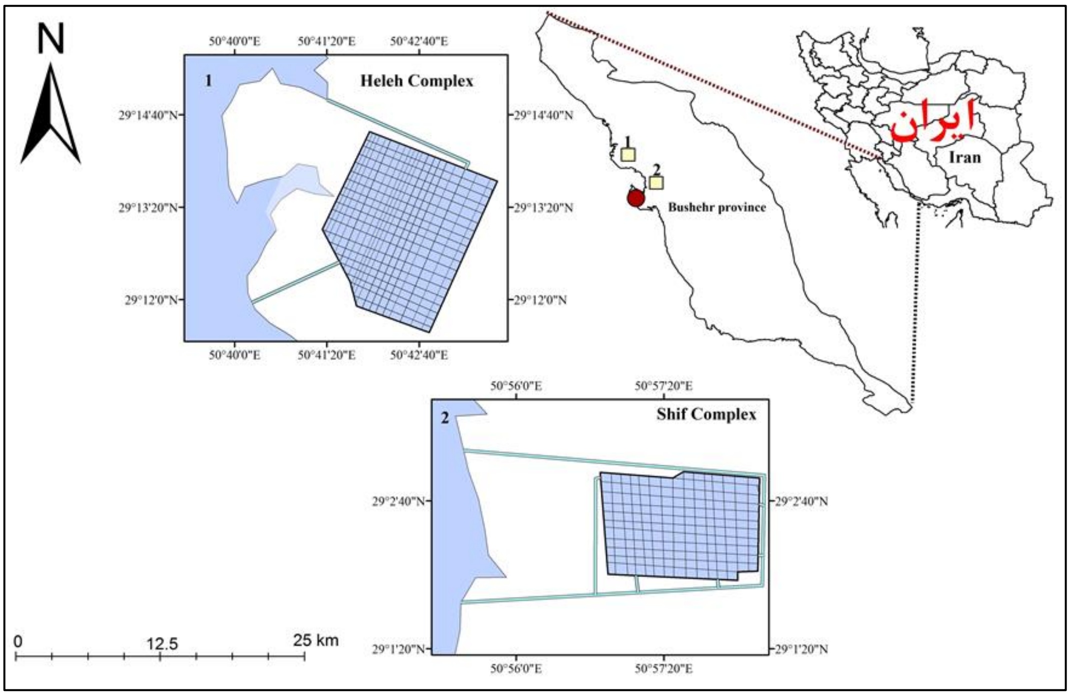

Figure 1: Geographical location of studied shrimp farming complexes (Delvar, Shif, and Heleh).

The Shif shrimp farming complex is located at 29˚04' N and 50˚57' E, about 30 kilometers northeast of Bushehr city. It covers an area of 2,169.6 hectares and includes 103 farms. The Heleh shrimp farming complex is located at 29˚13' N and 50˚44' E, approximately 110 kilometers northwest of Bushehr city. It is situated between two estuaries, Ghasir and Ramleh, at the end of the Heleh river in the Rig district of Genaveh city. It covers an area of 3,858 hectares and includes 67 farms. The water source for these complexes is gravity-fed from the sea through a canal, and it is pumped into the farms for use. In this study, three farms were selected from each shrimp farming complex, and three ponds were chosen from each farm for sampling and statistical purposes. In total, 18 ponds were sampled.

Growth performance

At the end of the shrimp farming cycle, body weight gain (BWG; g), feed conversion ratio (FCR), specific growth rate (SGR; %), Daily growth rate (g/day), and survival rate (SR; %) carried out using the following formulas:

$$\text{BWG (g)} = \text{Final weight} - \text{Initial weight}$$

$$\text{FCR} = {}^{\text{Feed given (g)}}\Big/_{\text{Alive weigh gain (g)}}$$

$$\text{SGR} = ({}^{\text{Ln(W2)} - \text{Ln(W1)}}/_{\text{Culture days}}) \times 100$$

$$\text{Daily growth rate } (\frac{\text{g}}{\text{day}}) = ({}^{\text{Average final weight} - \text{Average initial weight})}/_{\text{Days between sampling}}$$

$$\text{SR (\%)} = \left[{}^{\text{Final number of shrimp}}/_{\text{Initial number of shrimp}}\right]$$

Statistical analyses

The results of growth and production parameters were expressed as mean±standard deviation. One-way ANOVA was used to analyze the data, and then Duncan's test was performed to determine the significance of differences between treatments at the 0.05 level of probability. Pearson correlation was used to investigate the correlation between different parameters and production. Statistical analysis was performed using SPSS 22 software, and Excel software was used to draw graphs.

Results

The harvest yield from the studied shrimp farming complexes

The results of the yield harvest from the studied complexes in this study are shown in Figure 2. Out of a total of 18,800 tons harvested, the minimum and maximum yields were obtained from Heleh and Shif farms, with 6,200 tons (33%) and 12,600 tons (67%), respectively. Also, the minimum and maximum production per unit area were obtained from Heleh (7.22 tons per hectare) and Shif (7.43 tons per hectare) farms, respectively (Fig. 3).

Growth performance

The results of the present study on the average weight gain, mean daily growth rate, mean body weight, final yield harvest, survival rate percentage, FCR, SGR, Daily growth rate, and production per unit area (hectare) in the ponds of the shrimp farms studied in the Heleh and Shif complexes are presented in Figures 3 and 4.

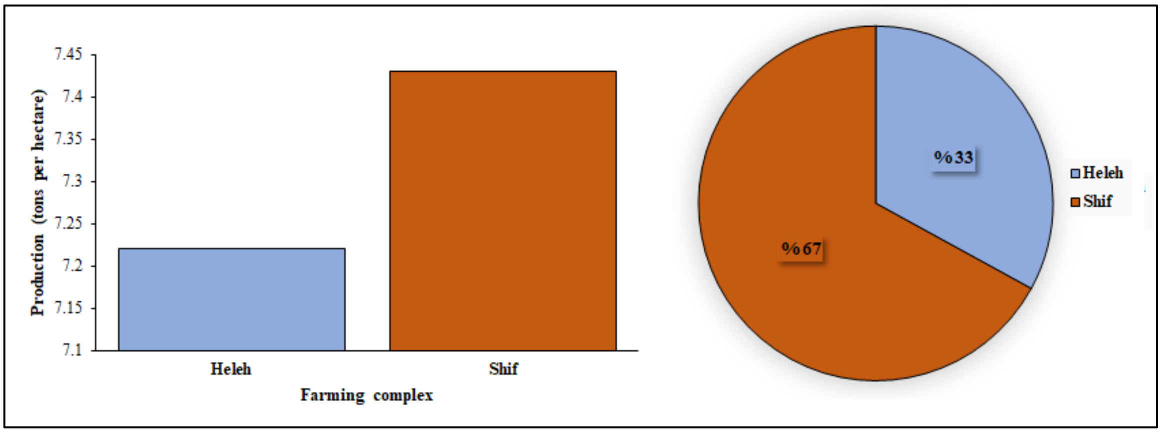

Figure 2: The percentage of harvest yield and production per unit area (tons per hectare) in Shif and Heleh complexes.

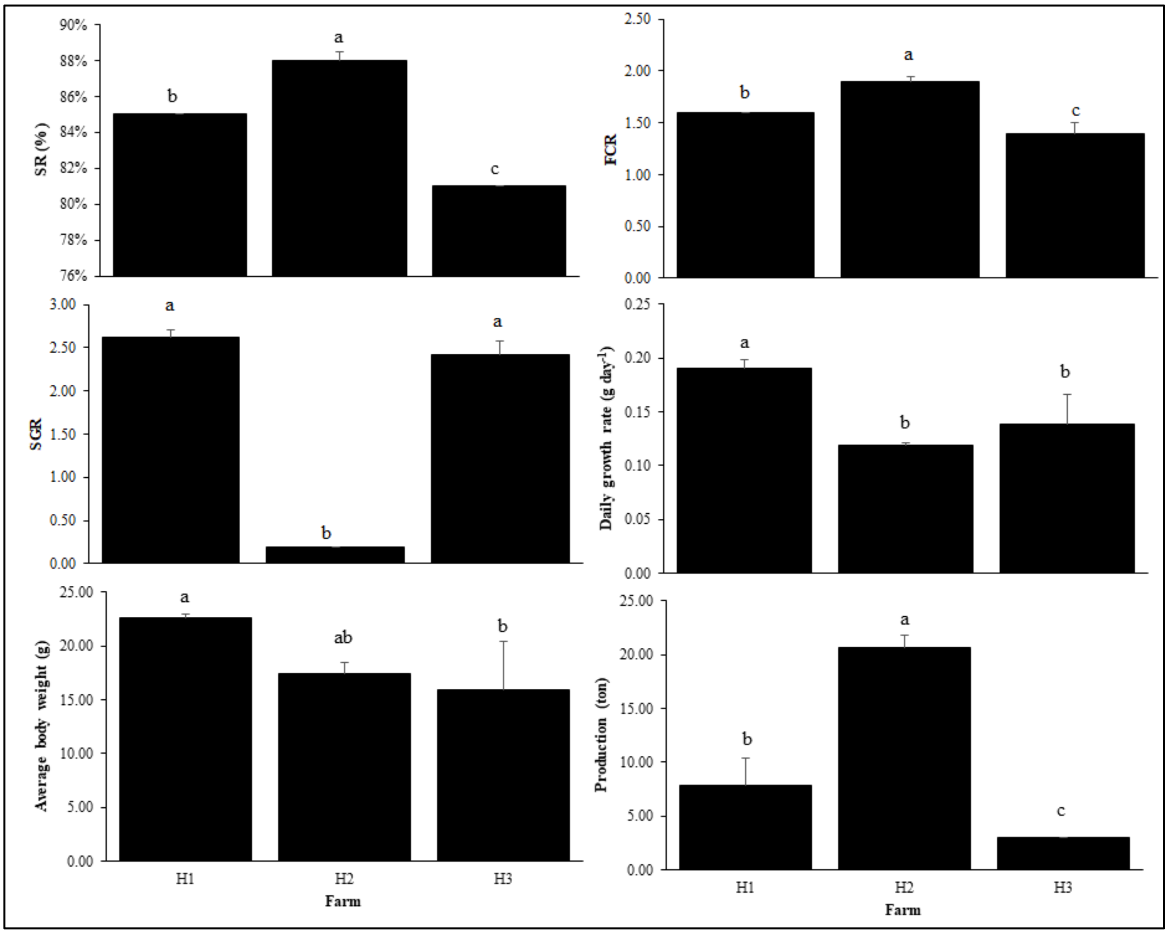

Figure 3: Growth and nutrition indices (mean ± standard deviation) of Pacific white shrimp (*Litopenaeus vannamei*) in the farms studied in the Heleh shrimp farming complex during one farming period in 2022.

Heleh complex

The results of the statistical analysis comparing means using the ANOVA test for average daily growth rate, mean body weight, final yield, SR, FCR, and SGR in different farms studied in the Heleh shrimp farming complex are presented in Figure 3. The results indicate significant differences ($p<0.05$) between different farms for the parameters under investigation.

Shif complex

The results of the statistical analysis comparing means for average daily growth rate, mean body weight, final yield (ton), SR (%), FCR, and SGR in different farms studied in the Shif shrimp farming complex are presented in Figure 4. The results did not show significant differences between different farms for average daily growth rate, FCR, and SGR (p>0.05). The SR (%) in different farms showed significant differences (p<0.05), with the minimum and maximum values obtained from farms S3 and S1, respectively. Moreover, the mean body weight and final yield showed significant differences (p<0.05) between farm S3 with farms S1 and S2.

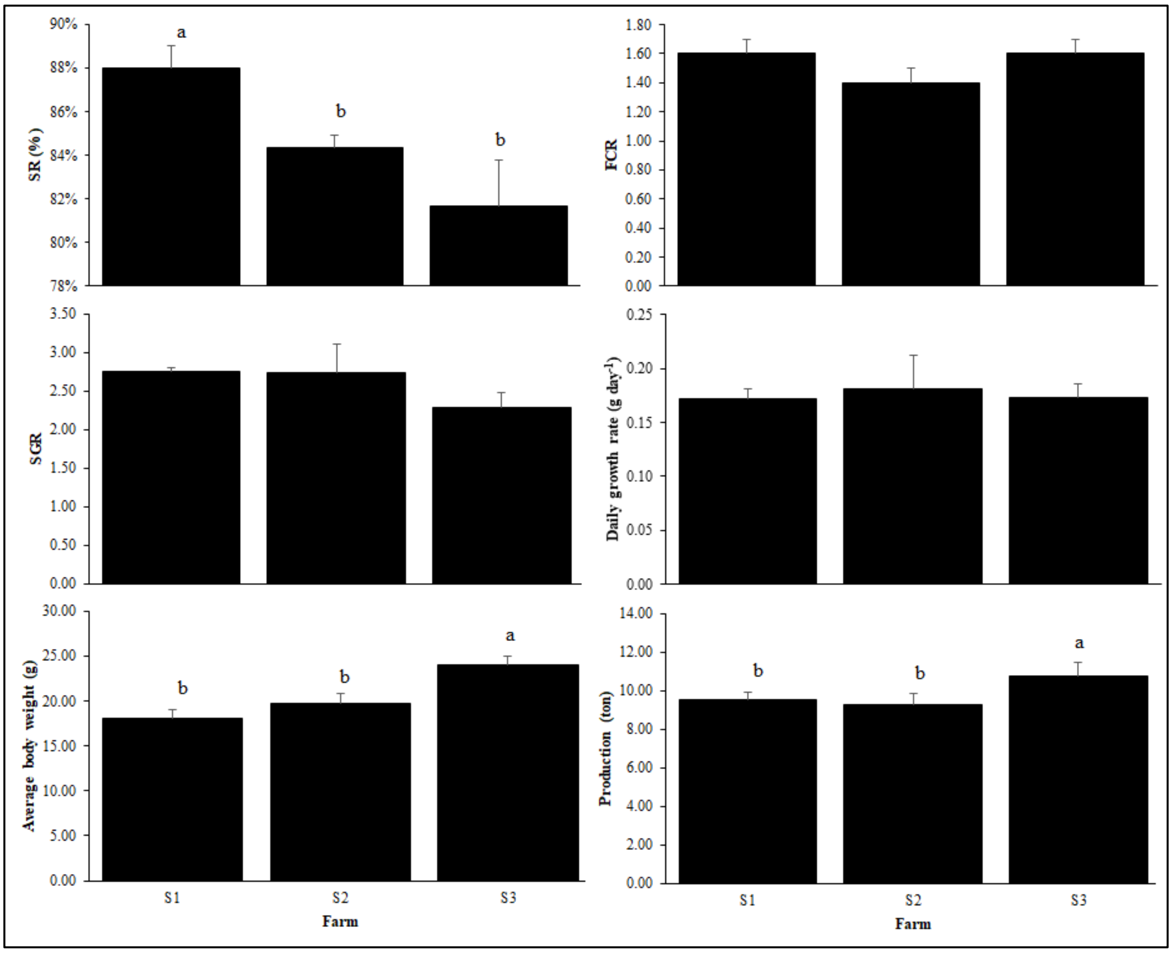

Figure 4: Growth and nutrition indices (mean ± standard deviation) of Pacific white shrimp (*Litopenaeus vannamei*) in the farms studied in the Shif shrimp farming complex during one farming period in 2022.

The relationship between different parameters

The results of Pearson correlation analysis between the stocking density, number of aerators, number of automatic feeders, and the culture period with the harvested yield are presented in Figure 5. According to the results, a high correlation (R>0.9) was observed between the production level and the stocking density, aeration rate, and culture period. Although the production level increased with increasing the number of automatic feeders, no significant correlation was found between these two parameters. In addition, a positive correlation was observed between the SR (%) and the stocking density and the number of aerators (Fig. 5).

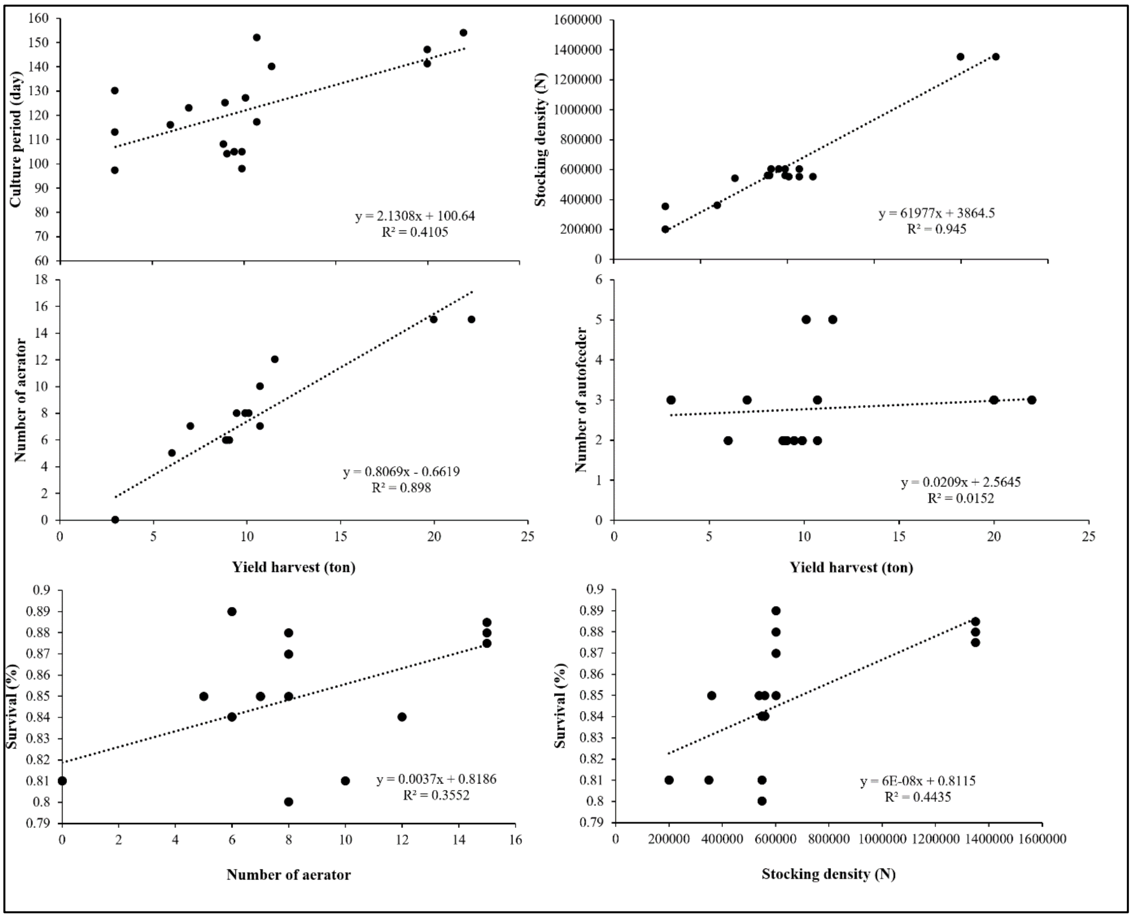

Figure 5: Pearson correlation analysis between the stocking post-larvae, number of aerators, number of automatic feeders, and the culture period with the production level and survival rate (%) with stocking density and number of aerators in the farms of Heleh and Shif complexes.

Discussion

The shrimp farming industry is at a pivotal juncture, where optimizing growth and yield production is not just a goal but a necessity for sustainability and economic viability. This comparative study of Pacific white shrimp farms along the Persian Gulf coastline sheds light on the intricate dynamics that govern shrimp cultivation. By meticulously analyzing various parameters such as stocking density, aeration rates, automatic feeder usage, and culture periods, we have unveiled critical insights that can significantly enhance production efficiency. The results of this study provide valuable insights into the factors that influence shrimp growth and yield in different shrimp farming complexes. The statistical analysis showed significant differences in the average daily growth rate, mean body weight, final yield, SR (%), FCR, and SG) between different farms in the Heleh shrimp farming complex. On the other hand, no significant differences were observed in average daily growth rate, FCR, and SGR between different farms in the Shif shrimp farming complex. However, significant differences were observed in SR (%), mean body weight, and final yield between different farms in the Shif complex.

The results of Pearson correlation analysis showed a high correlation between the production level and stocking density, aeration rate, and culture period. These findings suggest that the optimal stocking density, aeration rate, and culture period are critical factors for maximizing shrimp growth and yield. Furthermore, a positive correlation was observed between the SR (%), the stocking density, and the number of aerators. This indicates that higher stocking densities and aeration rates may result in better survival rates of shrimps. The lack of significant differences in some growth and yield parameters between different farms in the Shif complex may be due to similar environmental conditions, management practices, and/or genetic characteristics of the shrimps. In contrast, the significant differences observed in the Heleh complex could be attributed to differences in the aforementioned factors.

Several previous studies have reported similar findings on the effects of stocking density, aeration rate, and culture period on shrimp growth and yield (Sookying *et al*., 2011; Fleckenstein *et al.*, 2020*;* Lim *et al*., 2021). For example, a study conducted by Lim *et al*. (2021) found that increasing stocking density and aeration rate significantly improved shrimp growth and yield. Similarly, Robertson *et al*. (1993), Peixoto *et al*. (2018), and Carvalho and Nunes (2006) reported that optimizing culture period and feeding practices can enhance shrimp growth and yield.

The positive correlation between stocking density and shrimp yield observed in this study is consistent with the findings of other studies. For example, a study by Wasielesky *et al*. (2013) found that increasing stocking density resulted in higher shrimp biomass production. Similarly, a study by Kring *et al*. (2023) reported that high stocking densities can lead to increased shrimp yields, although this can also have negative impacts on water quality and environmental sustainability. The positive correlation between the aeration rate and shrimp survival rate observed in this study is also consistent with previous studies (McGraw *et al*., 2001; Harun *et al*., 2019). These studies reported that increasing aeration rates can improve water quality, shrimp growth, and survival rates.

Overall, the findings of this study provide further evidence to support the importance of optimizing stocking density, aeration rate, and culture period for maximizing shrimp growth and yield. However, it is important to consider the potential negative impacts of high stocking densities on water quality and environmental sustainability. Moreover, implementing sustainable shrimp farming practices, such as proper feeding practices and minimizing environmental impacts, can enhance the long-term economic and environmental viability of shrimp farming. Future research should focus on developing more efficient and sustainable shrimp farming practices that take into account these potential trade-offs.

Acknowledgments

This research was supported by a grant from the Iranian Fisheries Sciences Research Institute (12-80-12-056-00032-000789). The authors are also grateful to all colleagues at Iran Shrimp Research Center (ISRC) for their valuable assistance.

Confilicts of interest

The authors declare that they have no cconflicts of interest.

References

Anh, N.T.N., Murungu, D.K., Van Khanh, L. and Hai, T.N., 2022. Polyculture of sea grape (*Caulerpa lentillifera*) with different stocking densities of whiteleg shrimp (*Litopenaeus vannamei*): Effects on water quality, shrimp performance and sea grape proximate composition. *Algal Research*, 67, 102845. DOI: 10.1016/j.algal.2022.102845

Arambul-Muñoz, E., Ponce-Palafox, J.T., Claro De Los Santos, R., Aragón-Noriega, E.A., Rodríguez-Domínguez, G. and Castillo-Vargasmachuca, S.G., 2019. Influence of stocking density on production and water quality of a photoheterotrophic intensive system of white shrimp (*Penaeus vannamei*) in circular lined grow-out ponds, with minimal water replacement. *Latin American Journal of Aquatic Research*, 47(**3**), 449-455. DOI: 10.3856/vol47-issue3-fulltext-7

Araneda, M., Gasca-Leyva, E., Vela, M.A. and Domínguez-May, R., 2020. Effects of temperature and stocking density on intensive culture of Pacific white shrimp in freshwater. *Journal of Thermal Biology*, 94, 102756. DOI: 10.1016/j.jtherbio.2020.102756

Boyd, C.E., D'Abramo, L.R., Glencross, B.D., Huyben, D.C., Juarez, L.M., Lockwood, G.S., McNevin, A.A., Tacon, A.G., Teletchea, F. and Tomasso Jr, J.R., 2020. Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society*, 51(**3**), 578-633. DOI: 10.1111/jwas.12714

Bush, S.R., Pauwelussen, A., Badia, P., Kruk, S., Little, D., Newton, R., Nhan, D.T., Rahman, M.M., Sorgeloos, P. and Sung, Y.Y., 2021. Implementing aquaculture technology and innovation platforms in Asia. *Aquaculture*, 530, 735822. DOI: 10.1016/j.aquaculture.2020.735822

Carvalho, E.A. and Nunes, A.J., 2006. Effects of feeding frequency on feed leaching loss and grow-out patterns of the white shrimp *Litopenaeus vannamei* fed under a diurnal feeding regime in pond enclosures. *Aquaculture*, 252(**2-4**), 494-502. DOI: 10.1016/j.aquaculture.2005.07.013

Delphino, M.K., Laurin, E., Patanasatienkul, T., Rahardjo, R.B., Hakim, L., Zulfikar, W.G., Burnley, H., Hammell, K.L. and Thakur, K., 2022. Description of biosecurity practices on shrimp farms in Java, Lampung, and Banyuwangi, Indonesia. *Aquaculture*, 556, 738277. DOI: 10.1016/j.aquaculture.2022.738277.

Dey, K. and Sanyal, S., 2023. Sustainable development for shrimp culture: A critical analysis. In: Anil Kumar Patel, A.K., Singhania, R.R., Dong, C.D. and, Pandey, A. (eds) Sustainable marine food and feed production technologies. CRC Press, Boca Raton, Florida, United States. pp 103-120.

Dhar, A.R., Uddin, M.T. and Roy, M.K., 2020. Assessment of organic shrimp farming sustainability from economic and environmental viewpoints in Bangladesh. *Environmental Research*, 180, 108879. DOI: 10.1016/j.envres.2019.108879

Espinoza-Ortega, M., Molina-Poveda, C., Jover-Cerdá, M. and Civera-Cerecedo, R., 2023. Feeding frequency effect on water quality and growth of *Litopenaeus vannamei* fed extruded and pelleted diets. *Aquaculture International*, 1-17. DOI: 10.1007/s10499-023-01166-9

Fleckenstein, L.J., Kring, N.A., Tierney, T.W., Fisk, J.C., Lawson, B.C. and Ray, A.J., 2020. The effects of artificial substrate and stocking density on Pacific white shrimp (*Litopenaeus vannamei*) performance and water quality dynamics in high tunnel-based biofloc systems. *Aquacultural Engineering*, 90, 102093. DOI: 10.1016/j.aquaeng.2020.102093

Flegel, T.W., 2019. A future vision for disease control in shrimp aquaculture. *Journal of the World Aquaculture Society*, 50(**2**), 249-266. DOI: 10.1111/jwas.12589

Harun, A.A.C., Mohammad, N.A.H., Ikhwanuddin, M., Jauhari, I., Sohaili, J. and Kasan, N.A., 2019. Effect of different aeration units, nitrogen types and inoculum on biofloc formation for improvement of Pacific Whiteleg shrimp production. *The Egyptian Journal of Aquatic Research*, 45(**3**), 287-292. DOI: 10.1016/j.ejar.2019.07.001

Inayathullah, N., Vijayananad, P. and Srilaxmi, K., 2021. A comparative study on the shrimp culture practices of *Litopenaeus vannamei* with automatic feeder and boat feeding technique along Karaikal region. *Journal of Survey in Fisheries Sciences*, 101-110. DOI: 10.17762/sfs.v7i3.102

Izadpanahi, G., Nikouyan, A., Aein Jamshid, K., Oofi, F., Asadi Samani, N., Haghshenas, A., Mohammad Nejad, J., Omidi, S. and Pourang, N., 2005. Hydrology and hydrobiological study of the Persian Gulf in the Bushehr region. Final project report, Iranian Fisheries Research Organization.102 P. (In Persian)

Khanjani, M.H. and Sharifinia, M., 2020. Biofloc technology as a promising tool to improve aquaculture production. *Reviews in Aquaculture*, 12(**3**), 1836-1850. DOI: 10.1111/raq.12412

Khanjani, M.H. and Sharifinia, M., 2022. Biofloc as a food source for banana shrimp *Fenneropenaeus merguiensis* postlarvae. *North American Journal of Aquaculture*, 84(**4**), 469-479. DOI: 10.1002/naaq.10261

Khanjani, M.H., Sharifinia, M. and Emerenciano, M.G.C., 2023. A detailed look at the impacts of biofloc on immunological and hematological parameters and improving resistance to diseases. *Fish & Shellfish Immunology*, 137, 108796. DOI: 10.1016/j.fsi.2023.108796

Khanjani, M.H., Sharifinia, M., Akhavan-Bahabadi, M. and Emerenciano, M.G.C., 2024. Probiotics and Phytobiotics as Dietary and Water Supplements in Biofloc Aquaculture Systems. *Aquaculture Nutrition*, 2024(**1**), 3089887. DOI: 10.1155/anu/3089887

Kring, N.A., Fleckenstein, L.J., Tierney, T.W., Fisk, J.C., Lawson, B.C. and Ray, A.J., 2023. The effects of stocking density and artifical substrate on production of pacific white shrimp

Litopenaeus vannamei and water quality dynamics in greenhouse-based biofloc systems. *Aquacultural Engineering*, 101, 102322. DOI: 10.1016/j.aquaeng.2023.102322

Li, Y., Li, J. and Wang, Q., 2006. The effects of dissolved oxygen concentration and stocking density on growth and non-specific immunity factors in Chinese shrimp, *Fenneropenaeus chinensis*. *Aquaculture*, 256(**1-4**), 608-616. DOI: 10.1016/j.aquaculture.2006.02.036

Lightner, D.V., 2021. Noninfectious diseases of crustacea with an emphasis on cultured penaeid shrimp. In: Couch, J.A. and Fournie, J.W. (eds) Pathobiology of Marine and Estuarine Organisms. CRC Press, Boca Raton, Florida, United States. pp 343-358.

Lim, Y.S., Ganesan, P., Varman, M., Hamad, F. and Krishnasamy, S., 2021. Effects of microbubble aeration on water quality and growth performance of *Litopenaeus vannamei* in biofloc system. *Aquacultural Engineering*, 93, 102159. DOI: 10.1016/j.aquaeng.2021.102159

McGraw, W., Teichert-Coddington, D.R., Rouse, D.B. and Boyd, C.E., 2001. Higher minimum dissolved oxygen concentrations increase penaeid shrimp yields in earthen ponds. *Aquaculture*, 199(**3-4**), 311-321. DOI: 10.1016/S0044-8486(01)00530-0

N'Souvi, K., Sun, C., Che, B. and Vodounon, A., 2024. Shrimp industry in China: overview of the trends in the production, imports and exports during the last two decades, challenges, and outlook. *Frontiers in Sustainable Food Systems*, 7, 1287034. DOI: 10.3389/fsufs.2023.1287034

Peixoto, S., Silva, E., Costa, C., Nery, R., Rodrigues, F., Silva, J., Bezerra, R. and Soares, R., 2018. Effect of feeding frequency on growth and enzymatic activity of *Litopenaeus vannamei* during nursery phase in biofloc system. *Aquaculture Nutrition*, 24(**1**), 579-585. DOI: 10.1111/anu.12591

Robertson, L., Wrence, A.L. and Castille, F., 1993. Effect of feeding frequency and feeding time on growth of *Penaeus vannamei* (Boone). *Aquaculture Research*, 24(**1**), 1-6. DOI: 10.1111/j.1365-2109.1993.tb00823.x

Ruiz-Velazco, J.M., Hernández-Llamas, A. and Gomez-Muñoz, V.M., 2010. Management of stocking density, pond size, starting time of aeration, and duration of cultivation for intensive commercial production of shrimp *Litopenaeus vannamei*. *Aquacultural Engineering*, 43(**3**), 114-119. DOI: 10.1016/j.aquaeng.2010.08.002

Sharifinia, M., Bahmanbeigloo, Z.A., Keshavarzifard, M., Khanjani, M.H., Daliri, M., Koochaknejad, E. and Jasour, M.S., 2023a. The effects of replacing fishmeal by mealworm (*Tenebrio molitor*) on digestive enzymes activity and hepatopancreatic biochemical indices of *Litopenaeus vannamei*. *Annals of Animal Science*, 23(**2**), 519–528. DOI: 10.2478/aoas-2022-0098

Sharifinia, M., Bahmanbeigloo, Z.A., Keshavarzifard, M., Khanjani, M.H., Daliri, M., Koochaknejad, E. and Jasour, M.S., 2023b. Fishmeal replacement by mealworm (*Tenebrio molitor*) in diet of farmed Pacific white shrimp (*Litopenaeus vannamei*): effects on growth performance, serum biochemistry, and immune response.

Aquatic Living Resources, 36, 19. DOI: 10.1051/alr/2023013.

Sharifinia, M., 2024. Improve aquaculture with insect meal. *Science*, 383(**6685**), 838-838. DOI: 10.1126/science.ado0380

Sharifinia, M., 2025. From nutrient bioavailability to disease resistance: The comprehensive benefits of chelated minerals in aquaculture. *Fish & Shellfish Immunology*, 160, 110218. DOI: DOI: 10.1016/j.fsi.2025.110218

Sharifinia, M., Tayemeh, M., Dashtiannasab, A., Kaviani, A., Faghih, S., Pazir, M.K., Keshavarzifard, M., Aeinjamshid, K., Kalanaky, S., Fakharzade, S., Jand, Y. and Nazaran, M.H., 2024. Enhancement of growth performance, meat quality, digestive system, and immunity of *Litopenaeus vannamei* fed with advanced chelate compounds-based minerals: A new perspective on chelation technology. *Annals of Animal Science*, DOI:10.2478/aoas-2024-0104

Sookying, D., Silva, F.S.D., Davis, D.A. and Hanson, T.R., 2011. Effects of stocking density on the performance of Pacific white shrimp *Litopenaeus vannamei* cultured under pond and outdoor tank conditions using a high soybean meal diet. *Aquaculture*, 319(**1-2**), 232-239. DOI: 10.1016/j.aquaculture.2011.06.014

Suwoyo, H., Sahrijanna, A. and Pantjara, B., 2021. The nursery of Litopenaeus vannamei at different density using aeration system on pond. *IOP Conference Series: Earth and Environmental Science*, 012033.

Tacon, A.G. and Metian, M., 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, 285(**1-4**), 146-158. DOI: 10.1016/j.aquaculture.2008.08.015

Tien Nguyen, N., Tran-Nguyen, P.L. and Vo, T.T.B.C., 2024. Advances in aeration and wastewater treatment in shrimp farming: emerging trends, current challenges, and future perspectives. *AQUA-Water Infrastructure, Ecosystems and Society*, 73(**5**), 902-916. DOI: 10.2166/aqua.2024.328

Wasielesky, W., Froes, C., Fóes, G., Krummenauer, D., Lara, G. and Poersch, L., 2013. Nursery of *Litopenaeus vannamei* reared in a biofloc system: the effect of stocking densities and compensatory growth. *Journal of Shellfish Research*, 32(**3**), 799-806. DOI: 10.2983/035.032.0323

Westers, T., Ribble, C., Daniel, S., Checkley, S., Wu, J.P. and Stephen, C., 2017. Assessing and comparing relative farm-level sustainability of smallholder shrimp farms in two Sri Lankan provinces using indices developed from two methodological frameworks. *Ecological Indicators*, 83, 346-355. DOI: 10.1016/j.ecolind.2017.08.025

Yeganeh, V., Sharifinia, M., Mobaraki, S., Dashtiannasab, A., Aeinjamshid, K., Borazjani, J.M. and Maghsoudloo, T., 2020. Survey of survival rate and histological alterations of gills and hepatopancreas of the *Litopenaeus vannamei* juveniles caused by exposure of *Margalefidinium* / *Cochlodinium polykrikoides* isolated from the Persian Gulf. *Harmful Algae*, 97, 101856. DOI: DOI: 10.1016/j.hal.2020.101856