doi:http://doi.org/10.15578/jra.19.4.2024.331-343 *Jurnal Riset Akuakultur, 19 (4), 2024, 331-343*

EFFECTS OF FEEDING RATE REDUCTION ON THE GROWTH PERFORMANCE AND FEED UTILIZATION OF PACIFIC WHITE SHRIMP REARED USING BIOFLOC SYSTEM

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(Submission: 07 September 2024; Final revision: 03 March 2025; Accepted: 03 March 2025)

ABSTRACT

Biofloc used in shrimp aquaculture provides natural food and reduces the reliance on commercial feed. The extent to which biofloc can optimize feeding management is not, however, fully understood. This study aimed to evaluate the effects of reducing feeding rates on the growth performance and feed utilization of Pacific white shrimp (*Litopenaeus vannamei*) reared in a biofloc system. A completely randomized design was used with four treatments: K (standard feeding, clear water), N (standard feeding, biofloc), NA (25% feeding reduction, biofloc), and NB (50% feeding reduction, biofloc). Shrimp were stocked at 40 individuals per tank and fed commercial feed containing 40% protein over a 30-day period. Results showed that shrimp in the NA treatment (25% feed reduction with biofloc) had the highest final weight (8.66 ± 0.03 g), biomass (306.13 ± 14.27 g), and weight gain (5.74 ± 0.25 g) compared to other treatments (P<0.05). NA also exhibited a higher specific growth rate (3.63 ± 0.27 %/day) than K and NB. Feed utilization improved with a lower feed conversion ratio and higher protein retention in the NA group. This study highlights that a 25% feeding rate reduction in biofloc systems optimizes shrimp growth and feed utilization. Future research should explore long-term sustainability, biofloc composition variations, and technological integration for scaling up efficient and environmentally sustainable shrimp farming operations.

KEYWORDS: feed; feeding rate; growth; shrimp

ABSTRAK: Pengaruh Pengurangan Feeding Rate terhadap Kinerja Pertumbuhan dan Pemanfaatan Pakan Udang Vaname yang Dipelihara dengan Sistem Bioflok

Penggunaan bioflok dalam sbudidaya udang memberikan makanan alami dan mengurangi ketergantungan pada pakan komersial. Namun, sejauh mana bioflok dapat mengoptimalkan manajemen pakan belum sepenuhnya dipahami. Penelitian ini bertujuan untuk mengevaluasi efek pengurangan laju pemberian pakan terhadap kinerja pertumbuhan dan pemanfaatan

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*pakan udang vaname (**Litopenaeus vannamei**) yang dibudidayakan dalam sistem bioflok. Desain penelitian menggunakan rancangan acak lengkap (RAL) dengan empat perlakuan, yaitu: K (pemberian pakan standar, air jernih), N (pemberian pakan standar, bioflok), NA (pengurangan pakan 25%, bioflok), dan NB (pengurangan pakan 50%, bioflok). Udang ditempatkan sebanyak 40 individu per tangki dan diberi pakan komersial yang mengandung 40% protein selama 30 hari. Hasil menunjukkan bahwa udang pada perlakuan NA (pengurangan pakan 25% dengan bioflok) memiliki berat akhir tertinggi (8,66 ± 0,03 g), biomassa (306,13 ± 14,27 g), dan kenaikan berat (5,74 ± 0,25 g) dibandingkan perlakuan lainnya (P<0,05). NA juga menunjukkan tingkat pertumbuhan spesifik yang lebih tinggi (3,63 ± 0,27 %/hari) dibandingkan K dan NB. Pemanfaatan pakan meningkat dengan rasio konversi pakan yang lebih rendah dan retensi protein yang lebih tinggi pada kelompok NA. Penelitian ini menunjukkan bahwa pengurangan feeding rate pakan sebesar 25% dalam sistem bioflok mengoptimalkan pertumbuhan udang dan pemanfaatan pakan. Penelitian di masa depan harus mengeksplorasi keberlanjutan jangka panjang, variasi komposisi bioflok, dan integrasi teknologi untuk meningkatkan praktik budidaya udang yang efisien dan ramah lingkungan.*

KATA KUNCI: feeding rate; pakan, pertumbuhan, udang vaname

INTRODUCTION

The Pacific white shrimp (*Litopenaeus vannamei*) is a vital species in global aquaculture due to its fast growth, ability to thrive in various environmental conditions, and significant economic value (FAO, 2020; Panigrahi *et al.*, 2018). As shrimp demand continues to grow, the need for effective and sustainable farming practices becomes increasingly important. To maximize production, intensive culture systems with high stocking densities and reliance on manufactured feed are commonly employed. However, these systems have notable drawbacks, including the risk of disease outbreaks and water quality degradation caused by uneaten feed accumulation (Akbar & Fazli, 2023; Samadan *et al.*, 2018). Among various approaches, biofloc technology (BFT) has gained recognition as a sustainable and resource-efficient solution that enhances water quality. Additionally, it supplies extra nutrients through microbial biomass, reducing the dependency on external feed inputs (Barzamini *et al.*, 2021; Crab *et al.*, 2012; Emerenciano *et al.*, 2013a; Kurniaji *et al.*, 2023; Wasielesky Jr. *et al.*, 2006).

Biofloc systems are highly beneficial in intensive aquaculture where the cost of feed often exceeds 50% of total costs (Padeniya *et al.*, 2022). Overfeeding can not only increases expenses, but can also leads to deteriorating water quality due to the accumulation of uneaten feed and shrimp waste. This can have a negative impact on shrimp health and growth (Rupiwardani *et al.*, 2023). Artificial feed contains 30-40% crude protein which contributes 90% of protein in ponds with only 20-25% being processed into shrimp biomass. Approximately 14% of crude protein accumulates in the sediment and 57% remains in the pond water as organic waste (Iber & Kasan, 2021; Prasetiyono & Bidayani, 2022). The decomposition of organic waste can create anoxic pond conditions which are toxic to shrimp and can lead to mass mortality (Iber & Kasan, 2021; Prachumwat *et al.*, 2020). Flocs in the water column can also reduce feed costs by providing additional food for cultured species which can account for 40-60% of total expenses for intensive farms (Rego *et al.*, 2017). For example, tilapia raised in a biofloc system experienced a 33% reduction in production costs (Megahed, 2010). Enhancing feeding strategies within biofloc systems can therefore boost both growth performance and feed efficiency while reducing environmental impacts. Studies have demonstrated that applying a feeding rate strategy with minimal feed input led to improved growth performance in Pacific white shrimp cultured in the biofloc system compared to those receiving the maximum feed amount (da Silva *et al.*, 2022). Additionally, shrimp groups subjected to a lower feeding rate showed reduced levels of toxic nitrogen compounds and total suspended solids compared to those fed at a higher rate (Padilla *et al.*, 2024).

Reducing feeding rates in biofloc systems is a key strategy for aquaculturists seeking to enhance sustainability. Biofloc serves as an alternative protein source, allowing shrimp to be cultured with lower protein levels without negatively impacting their growth and survival (Lee *et al.*, 2017; Samocha *et al.*, 2004; Xu & Pan, 2012; Yassien *et al.*, 2021). However, determining the optimal feeding rate is crucial, as excessive feed reduction may limit nutrient availability and impair shrimp growth performance (Chaikaew *et al.*, 2019). Research has shown that biofloc can replace up to 29% of the shrimp's daily feed intake, depending on its quality and quantity (Burford *et al.*, 2004). Additionally, biofloc contains 30% protein and 2% lipid (Luo *et al.*, 2014; Xu & Pan, 2012), which can substitute a significant portion of dietary protein (Sharawy *et al.*, 2022; Yun *et al.*, 2016). Cultivating white shrimp in a biofloc system has been found to reduce dietary protein levels from 450 to 350 g protein kg^{-1} while enhancing growth performance and feed utilization (Mansour *et al.*, 2022).

This study aims to assess the effects of reduced feeding rates on the growth and feed utilization of Pacific white shrimp in a biofloc system. By evaluating different levels of feed reduction, this research seeks to identify optimal feeding strategies that promote shrimp growth, improve feed efficiency, and reduce feed waste. Additionally, it provides insights into how feeding rate adjustments influence shrimp growth, biofloc system productivity, and overall sustainability, contributing to the development of more environmentally friendly aquaculture practices.

MATERIALS AND METHODS

Experimental Design

This study utilized an experimental approach employing a completely randomized design (CRD) with four treatment groups and three replicates, totaling 12 experimental units. Each treatment involved varying feeding rates for Pacific white shrimp cultured in a biofloc system. The treatments were as follows: Control (standard feeding rate without biofloc), N (standard feeding rate with biofloc), NA (standard feeding rate reduced by 25% with biofloc), and NB (standard feeding rate reduced by 50% with biofloc). The standard feeding rate used was based on the shrimp feeding procedure explained by Van Wyk & Scarpa (1999).

Preparation of Rearing Media and Test Animals

The rearing media used were glass aquariums (60 x 40 x 50 cm^3). The aquariums were thoroughly washed and sterilized before the experiment using 30 ppm chlorine followed by aeration for 24 hours. The aquariums were then filled with sterilized seawater after drying. Glass aquariums (60 x 40 x 50 cm^3) used for rearing were thoroughly washed and sterilized using 30 ppm chlorine before the experiment. These were subsequently aerated for 24 hours and filled with sterilized seawater. Biofloc formation was started 7 days before the experiment according to Widanarni *et al.* (2012) with a carbon-to-nitrogen (C/N) ratio of 10 using molasses as the carbon source. A commercial probiotic (*Paraqua Biofloc* produced by CV. Pradipta Paramita in Karanganyar, Indonesia) was added at a dose of 5 $g.m^{-3}$ to enhance biofloc formation. The Pacific white shrimp (test animals) were obtained from a local farm (Koperasi Cahaya Mina PKPJ in

Jembrana, Indonesia) with a weight of 1.0-1.5 g. The shrimp were acclimated in 285 x 285 x 100 cm^3 tanks for two weeks before being introduced to the experimental aquariums. The shrimp were fed commercial feed with 32% protein content during this period at a feeding rate of 8% of biomass. Feed was administered four times daily at 08:00, 12:00, 16:00, and 20:00 Central Indonesian Time.

Rearing of Test Animals

Shrimp weighing an average of 2-3 g were randomly distributed into 12 aquariums, each containing 96 liters of seawater at a stocking density of 40 shrimp per aquarium. The rearing period lasted 30 days, during which the shrimp were fed four times daily at 08:00, 12:00, 16:00, and 20:00 WITA. The feeding rate was adjusted based on the average shrimp weight obtained from samplings conducted every 10 days following guidelines explained by Van Wyk & Scarpa (1999). Molasses was added daily two hours after the morning feeding, and probiotics were added weekly at a dose of 5 $g.m^{-3}$.

Growth Performance and Feed Utilization Observations

Growth performance parameters evaluated in this study included final weight, final biomass, weight gain, specific growth rate (SGR), and survival rate. Feed utilization was assessed through the feed conversion ratio (FCR), final protein content in the whole shrimp body, and protein retention. Measurements for final weight, final biomass, weight gain, SGR, FCR, and survival rate were determined based on shrimp sampling conducted every 10 days throughout the experiment. Analysis of the final protein content in the whole shrimp body was performed using the Kjeldahl method (Association of Official Analytical Chemists, 1995). Protein retention was evaluated by comparing the protein content of the feed with that of the shrimp (Maicá *et al.*, 2014).

Water Quality Measurement

Water quality parameters such as temperature, salinity, dissolved oxygen, pH and total ammonia nitrogen (TAN) were measured during this experiment. Temperature, salinity, dissolved oxygen, and pH were measured daily, while TAN concentration was measured every 10 days using a marine test kit (Salifert®, Salifert, Duive, the Netherlands).

Data Analysis

The data analysis was conducted using Microsoft Excel 2021 and SPSS version 25.0. Levene's test and the Shapiro-Wilk test were used to assess variance homogeneity and data normality. A one-way ANOVA was applied to evaluate growth performance and feed utilization, followed by Duncan's multiple range test at a 95% confidence level. Water quality data were analyzed using descriptive statistics.

RESULTS AND DISCUSSION

Growth Performance

Statistical analysis revealed significant differences among treatments for most growth parameters (Table 1). Reducing the feeding rate by 25% in the biofloc system (NA treatment) resulted in better growth performance and biomass production compared to both standard feeding and a 50% feed reduction. The use of biofloc was found to enhance shrimp growth by providing additional microbial nutrients, allowing for a reduction in commercial feed without compromising performance. Excessive feed reduction, as observed in the NB treatment, led to reduced growth and weight gain. This highlights the importance of optimizing feeding strategies in biofloc systems to achieve a balance between growth and sustainability.

The final weight of shrimp was significantly higher in the NA treatment (25% feeding reduction with biofloc) at 8.66 ±

Table 1. Growth performance of Pacific white shrimp reared using the biofloc system under different levels of feeding rate reduction

Parameters	Treatments			
	K	N	NA	NB
Final weight (g.shrimp^{-1})	6.55 ± 0.08[a]	7.69 ± 0.20[b]	8.66 ± 0.03[c]	6.37 ± 0.35[a]
Biomass (g)	216.01 ± 12.42[a]	233.07 ± 6.00[a]	306.13 ± 14.27[b]	212.22 ± 12.39[a]
Weight gain (g)	3.59 ± 0.18[a]	4.84 ± 0.28[b]	5.74 ± 0.25[c]	3.36 ± 0.41[a]
Specific growth rate (%.day^{-1})	2.65 ± 0.17[a]	3.31 ± 0.23[b]	3.63 ± 0.27[b]	2.50 ± 0.26[a]
Survival rate (%)	82.50 ± 5.00[ab]	75.83 ± 3.82[a]	88.33 ± 3.82[b]	83.33 ± 3.82[ab]

Data are presented as mean ± SD. Different superscript letters in the same row indicate significant differences (P<0.05). K (control: standard feeding rate without biofloc), N (standard feeding rate with biofloc), NA (standard feeding rate reduced by 25% with biofloc), and NB (standard feeding rate reduced by 50% with biofloc)

0.03 g compared to all other treatments (P < 0.05). This suggests that a moderate feeding reduction with biofloc significantly improved growth. The N treatment (normal feeding rate with biofloc) also performed better than the control (K), suggesting that biofloc enhances nutrient availability and shrimp growth. The NB treatment (50% feed reduction) yielded a lower final weight (6.37 ± 0.35 g) similar to the control. This suggests that excessive feed reduction negatively affects growth.

Biomass followed a similar pattern, with the NA treatment yielding the highest biomass (306.13 ± 14.27 g), which was significantly greater than that of the other treatments (P < 0.05). These findings are consistent with those reported by Padilla *et al.* (2024), which indicated that reducing feeding rates to a minimum resulted in no significant difference in the final biomass of Pacific white shrimp compared to maximum feeding rates. That study used a feeding table developed by Van Wyk & Scarpa (1999), which categorized feeding levels as minimum -10%, minimum, maximum, and maximum +10%. The present study suggests that reducing the feeding rate by 25% from the table established by Van Wyk & Scarpa (1999) in biofloc-based shrimp farming is feasible without negatively impacting growth performance. Biofloc serves as a supplementary feed source for shrimp, as it is rich in vitamins, minerals, proteins, and lipids (Avnimelech, 2009). Additionally, biofloc can function as live feed and be integrated into aquaculture systems alongside artificial feed (Khanjani *et al.*, 2019). Research has further shown that Pacific white shrimp exhibit superior growth when fed a combination of artificial feed and biofloc rather than relying solely on one or the other (Caldini *et al.*, 2015; Khanjani *et al.*, 2016). This advantage may stem from the shrimp's ability to utilize the natural productivity of the biofloc system (Samocha *et al.*, 2017).

The NA treatment group also demonstrated the highest weight gain (5.74 ± 0.25 g), which was significantly higher than that observed in all other treatments ($P < 0.05$). Conversely, the NB group recorded the lowest weight gain (3.36 ± 0.41 g), comparable to the control group. These results suggest that a moderate reduction in feeding rates for Pacific white shrimp reared in biofloc systems can enhance growth performance more effectively than higher feeding rates. However, excessive feed reduction resulted in suboptimal growth. Previous research has shown that shrimp receiving an optimal feed amount tend to exhibit better growth (da Silva *et al.*, 2022). Biofloc contains microbial protein, polyhydroxybutyrate (PHB), and bacteria with peptidoglycan and lipopolysaccharide in their cell walls, which contribute to improved growth in cultured species (Supono *et al.*, 2014). The role of biofloc as a natural feed source is further reflected in enhanced weight gain and feed conversion ratio (FCR) in shrimp (Becerril-Cortés *et al.*, 2018).

The specific growth rate (SGR) was highest in the NA treatment (3.63 ± 0.27% day^{-1}), which was significantly different ($P < 0.05$) from the control (2.65 ± 0.17% day^{-1}) and NB treatment (2.50 ± 0.26% day^{-1}) but not from the N treatment. These results align with findings from Kim *et al.* (2015), which demonstrated that Pacific white shrimp reared in a biofloc system achieved significantly higher SGR compared to those cultured in clear seawater. The dominant bacterial genus present in biofloc, *Bacillus*, has been shown to aid digestion and nutrient absorption in shrimp, leading to improved growth performance (Vidal *et al.*, 2018).

Survival rates showed slight variations among treatments. The NA group recorded the highest survival rate at 88.33 ± 3.82%, but this was not significantly different ($P > 0.05$) from the control or NB treatments. The N treatment, which followed a normal feeding rate with biofloc, had the lowest survival rate at 75.83 ± 3.82%. These findings suggest that the biofloc system does not have adverse effects on shrimp survival. Reported survival rates in biofloc-based shrimp farming typically range from 66% to 99% (Krummenauer *et al.*, 2014a; Krummenauer *et al.*, 2014b; Maicá *et al.*, 2014). A lower feed supply within a biofloc system can increase cannibalism, whereas higher nutrient availability and feed input tend to improve survival rates (Khanjani *et al.*, 2019).

Feed Utilization

Data from this study showed significant differences in feed conversion ratios (FCR), final protein content and protein retention across treatments as analyzed using one-way ANOVA and Duncan's test (Table 2). The results suggest a 25% reduction in feeding rate (NA treatment) with biofloc improved growth performance and also optimized feed efficiency and protein retention. Additionally, the 50% feed reduction (NB treatment) led to the most efficient feed utilization (lowest FCR), although it may not maximize protein accumulation in shrimp. These findings demonstrate the potential of biofloc technology to reduce feed inputs while maintaining or improving shrimp production efficiency.

The feed conversion ratio (FCR) results indicated that the NB treatment (50% feed reduction with biofloc) had the lowest FCR (0.71 ± 0.04), which was significantly lower than all other treatments ($P < 0.05$). This suggests that shrimp in the NB group utilized their feed most efficiently. The NA treatment (25% feed reduction with biofloc) also demonstrated a favorable FCR (0.90 ± 0.04), reflecting improved feed efficiency compared to the control (K) and the standard feeding rate with biofloc (N) treatments. These findings are consistent with the study by Padilla *et al.* (2024), which reported that the lowest feeding rate resulted in an improved FCR during the nursery phase of Pacific white shrimp. This suggests that feed intake can be reduced in biofloc-based shrimp farming without compromising productivity. Such an approach could be particularly beneficial in super-intensive shrimp operations, where feed costs account for more than 60% of total operational expenses (Almeida *et al.*, 2022). Biofloc is rich in essential minerals such as zinc, iron, calcium, magnesium, and sodium, which contribute to improved feed utilization in shrimp (Uawisetwathana *et al.*, 2021). Several studies have also reported lower FCR values in biofloc systems compared to traditional clear-water systems (Adipu *et al.*, 2019; Emerenciano *et al.*, 2013b; Krummenauer *et al.*, 2014a; Xu & Pan, 2012).

Although the initial protein content was uniform across all treatments due to the use of the same feed, there were significant differences in the final protein content. The NA treatment resulted in the highest final protein content (61.86 ± 2.45 g), which was significantly greater than that observed in the K and N treatments. This indicates that shrimp in the NA group not only exhibited better growth but also retained more

Table 2. Feed utilization of Pacific white shrimp reared using the biofloc system under different levels of feeding rate reduction

Parameters	Treatments			
	K	N	NA	NB
Feed conversion ratio	1.74 ± 0.10[d]	1.61 ± 0.04[c]	0.90 ± 0.04[b]	0.71 ± 0.04[a]
Initial protein content (g)	21.66 ± 0.90[a]	20.86 ± 1.28[a]	21.41 ± 1.75[a]	22.02 ± 0.83[a]
Final protein content (g)	44.89 ± 2.89[a]	47.39 ± 2.05[a]	61.86 ± 2.45[b]	42.58 ± 2.46[a]
Protein retention (%)	16.41 ± 1.82[a]	17.70 ± 0.97[a]	18.94 ± 1.19[b]	18.73 ± 1.44[b]

Data are presented as mean ± SD. Different superscript letters in the same row indicate significant differences ($P<0.05$). K (control: standard feeding rate without biofloc), N (standard feeding rate with biofloc), NA (standard feeding rate reduced by 25% with biofloc), and NB (standard feeding rate reduced by 50% with biofloc)

dietary protein. Microorganisms in biofloc provide valuable proteins, lipids, minerals, and vitamins for cultured species, along with exogenous enzymes that aid digestion (Becerril-Cortés *et al.*, 2018). Previous studies have reported higher biochemical compound levels in shrimp cultured in biofloc systems compared to conventional systems, likely due to the presence of amino acids, fatty acids, and other nutrients found in biofloc (Khanjani *et al.*, 2017). The nutritional quality of biofloc can be influenced by various environmental factors, including temperature, aeration, dissolved oxygen, carbon source, total suspended solids, salinity, stocking density, light intensity, pH, and microbial community composition (Avnimelech, 2007; De Schryver *et al.*, 2008; Khanjani *et al.*, 2017; Martínez-Córdova *et al.*, 2015).

Protein retention, which serves as a key measure of how efficiently dietary protein is utilized and incorporated into shrimp biomass, was highest in the NA (18.94 ± 1.19%) and NB (18.73 ± 1.44%) treatments. Both values were significantly higher than those observed in the control and N treatments ($P < 0.05$). The high protein retention in the NA and NB groups suggests that biofloc supplementation enables feed reduction without impairing shrimp's ability to effectively retain and utilize protein. The biofloc system enhances protein utilization by converting a greater proportion of dietary nutrients into shrimp body mass (Hwihy *et al.*, 2021).

Water Quality

The water quality parameters monitored in this study, including salinity, temperature, pH, dissolved oxygen, and total ammonia nitrogen (TAN), are summarized in Table 3. These factors are crucial for the health and growth of Pacific white shrimp. Ensuring stable water conditions is vital for maximizing shrimp production, and the biofloc system appears to offer a more consistent environment compared to clear-water or control systems.

The salinity levels in all treatments remained within the acceptable range for shrimp farming, with relative stability observed throughout the experiment, particularly in the NA treatment (29-37 ppt). Pacific white shrimp can tolerate salinity levels between 5-40 ppt (Saoud *et al.*, 2003), though the optimal range for those reared in biofloc systems is 26-32 ppt (Panigrahi *et al.*, 2020). Variations in salinity can influence the microbial composition in biofloc systems (Emerenciano *et al.*, 2011). Hosain *et al.* (2021) reported that chlorophytes were more abundant at a salinity of 5 ppt, whereas diatoms thrived at 32 ppt. Maintaining salinity around 32 ppt is beneficial for shrimp cultivation as it ensures an adequate supply of diatoms, which serve as a food source. Temperature is another crucial factor, as shrimp are highly sensitive to fluctuations. The recorded temperatures in all treatments fell within the optimal range of 28-32°C for Pacific white shrimp (Uawisetwathana *et al.*, 2021).

Table 3. Water quality of the rearing media of Pacific white shrimp reared using the biofloc system under different levels of feeding rate reduction

Parameters	Treatments				Optimum range
	K	N	NA	NB	
Salinity (ppt)	29-38	30-39	29-37	29-39	26-32***
Temperature (°C)	24.2-27.3	24.3-27.4	24.3-27.6	24.2-27.9	28-32****
pH	7.66-9.87	7.09-8.17	6.81-8.22	7.92-8.32	7-9**
Dissolved oxygen ($mg.L^{-1}$)	3.5-8.0	3.2-8.2	3.5-8.1	3.6-8.7	> 5*
Total ammonia nitrogen ($mg.L^{-1}$)	0.15-0.50	0.15-0.50	0.15-0.50	0.15-0.50	≤ 0.1***

Data are presented as minimum-maximum values during the experiment. K (control: standard feeding rate without biofloc), N (standard feeding rate with biofloc), NA (standard feeding rate reduced by 25% with biofloc), and NB (standard feeding rate reduced by 50% with biofloc). *Crab *et al.* (2012); **Khanjani *et al.* (2019); ***Ministry of Marine Affairs and Fisheries (2016); ****Uawisetwathana *et al.* (2021)

The pH levels were more stable in biofloc treatments, showing less variability compared to the control group (K), which exhibited a wider pH range. The presence of autotrophic, heterotrophic, and chemosynthetic bacteria in the biofloc system contributes to alkalinity consumption, leading to reduced pH and alkalinity levels (Brito *et al.*, 2014). Additionally, the introduction of an external carbon source into the rearing environment can further lower pH levels in biofloc systems (Maicá *et al.*, 2014).

Dissolved oxygen (DO) levels remained stable across all treatments, ranging from 3.2 to 8.7 $mg.L^{-1}$. To sustain a healthy microbial community and farmed species, DO levels in biofloc systems should be maintained above 5 $mg.L^{-1}$ (Crab *et al.*, 2012). Aeration is essential in biofloc systems as it helps keep floc particles suspended and supports nitrification by facilitating the activity of ammonia-oxidizing and nitrite-oxidizing bacteria. This process enhances floc formation and improves microbial performance (Anjalee-Devi & Madhusoodana, 2015; Kuhn & Lawrence, 2015).

Total ammonia nitrogen (TAN) levels were effectively controlled in all treatments, ranging from 0.15 to 0.50 $mg.L^{-1}$. In biofloc systems, heterotrophic bacteria and diatoms assimilate ammonia, converting it into microbial biomass. Concurrently, nitrifying bacteria transform ammonia into nitrite and subsequently into nitrate (Amin *et al.*, 2012; Emerenciano *et al.*, 2017; Kirchman, 1994).

CONCLUSION

Moderate reduction in feeding rate (25%) with biofloc (NA) displayed the best overall growth performance (final weight, weight gain, and biomass) while the 50% reduction (NB) led to the most efficient feed utilization (lowest FCR). Protein retention was highest in both reduced feeding rate groups (NA and NB) which demonstrated that feeding rate reductions combined with the use of biofloc systems optimize both growth and feed efficiency.

ACKNOWLEDGMENTS

The authors sincerely appreciate the Ministry of Marine Affairs and Fisheries of Republic of Indonesia for financially supporting this research through the BIMA KKP research grant. We are also deeply grateful to the students of the Department of Aquaculture, Batch VI, for their dedication and assistance in various aspects of this study.

FUNDING

This study was financially supported by the BIMA KKP research grant from the Ministry of Marine Affairs and Fisheries of Republic of Indonesia under contract number 365/PPK.PUSDIK/PL.430/V/2024.

AUTHOR CONTRIBUTION

We confirm that the role of each author (abbreaviate name) as the following based on CRedit taxonomy (https://credit.niso.org/):

AK: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing; DASU: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review and editing; TH: Conceptualization, Methodology; ST: Conceptualization, Methodology; MST: Conceptualization, Methodology; TF: Project administration, Investigation, Resources; YEK: Project administration, Investigation, Resources; RD: Conceptualization, Methodology; UT: Conceptualization, Methodology; MAS: Project administration, Investigation, Resources.

DECLARATION OF COMPETING INTEREST

The authors confirm that there are no conflicts of interest associated with this research or the preparation of this article. All authors have reviewed and approved the content for publication in the Jurnal Riset Akuakultur.

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