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Optimal Feeding Frequency on the Growth Performance of Whiteleg Shrimp (*Litopenaeus vannamei*) during Grow-out Phase

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Abstract

Whiteleg shrimp (*Litopenaeus vannamei*) is a fisheries commodity that has experienced a vast increase in production since the early 1970s. As one of the largest contributors to the global shrimp market, Indonesia always tried to increase its shrimp production. To fulfill the global market demand, whiteleg shrimp farmers have met with countless obstacles, e.g., sub-optimal growth problem. Optimal feed management is one of the determining factors that account for the growth and production efficiency of whiteleg shrimp. Feed management practices include feeding frequency, methods of feed monitoring, and controlling. This literature review aims to provide an insight into the optimal feeding frequency for the growth, survival, and feed efficiency of whiteleg shrimp production. The method used for this review was a narrative review approach following the PRISMA scheme for literature sorting, which includes identification, screening, eligibility test, and inclusion. There were eight primary literatures from journals with H indices of 18, 50, 55, 72, 80, and 164 (four articles from Q1 journals and three from Q2 journals) and one article without index. Data analysis revealed that the growth rate was significantly affected by the feeding frequency of on-demand feeding system (AQ1) ($P < 0.05$), although no significant difference was found in regards to the survival rate and the FCR ($P > 0.05$). The optimal feeding frequency for industrial-scale shrimp production was found in the on-demand feeding system (AQ1).

Keywords: frequency, feed, growth, survival, FCR, *Litopenaeus vannamei*

1. Introduction

During five years of 2013 - 2017, The Central Statistics Department (Badan Pusat Statistik) has noted an average annual growth of 6.43% on whiteleg shrimp (*L. vannamei*) export. According to the Ministry of Oceanography and Fisheries' data, the export volume from 2017 alone amounted to 147 thousand tons and increased in the following year up to 180 thousand tons [1]. In 2018, Indonesia is the 6th largest exporter of whiteleg shrimp on a global scale. The global market volume of shrimps amounts to 4.66 million tons in 2018, with the whiteleg shrimp being the main commodity. According to Research and Markets [2], the growth of global shrimp market is currently at a CAGR (compound annual growth rate) of 3.7% and the volume is predicted to reach 5.83 million tons in 2024. This indicates a vast development in the fisheries industry, especially in regards to whiteleg shrimp commodity. In response to that opportunity, the Ministry of Oceanography and Fisheries initiated a program called '*Percepatan Pengembangan Tambak Udang Nasional,'* aimed to accelerate the production of whiteleg shrimp to better equip Indonesia to compete in the global market, with a target of 1.29 million tons of product by 2024 [1].

Feed is one of the biggest contributory components in the success or failure of shrimp farming, with its share as the main source of balanced nutrition for shrimp. In a study by Tacon & Metian [3], in 2012 shrimp feed was in the third position (6.18 million tons) of the largest commodity feed production globally, after the first order of carp feed (11.03 million tons) and both tilapia feed (6.67 million tons). In each report on the operation of commodity cultivation, it can be ascertained that feed is the largest contribution to operational costs, at least 50-60% of the total costs incurred per cycle [4]. In addition to being named the biggest factor in economic efficiency, improper feed management is the main cause of water quality degradation in aquaculture, which will indirectly require more maintenance or mitigation costs. Boyd et al.

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[5] estimated that only about 10-30% of nutrients in feed are absorbed by the digestive system of commodity animals, while the rest is trapped in water in the form of untouched feed, feces, or excretion products.

Using feed with balanced nutrition and implementing feed management is the key to efficient cultivation economically and environmentally friendly [6]. In general, it has been agreed that the use of high-quality feed is highly recommended because the operational costs will be more efficient. After all, the absorption of nutrients will be more optimal and the accumulation of nutrients in the water will be much reduced. Shipton & Hasan [7] found that feed with a formulation that is not under the nutritional needs of commodity animals will lead to inefficient cultivation and increase production costs. The use of high-quality feed with appropriate formulations is a prerequisite for profitable cultivation, but ultimately the success of cultivation will depend on the application of proper feed management [8, 9].

Effective feed management strategy requires the consideration of the shrimp's physiology on the feeding behaviour and digestion [8]. According to Cardona et al. [10], feeding frequency affects enzymatic activity in shrimp's digestion, which will accelerate the digestion process and ultimately the shrimp's growth. The study conducted by Peixoto et al. [11] have proven that feeding frequency affects digestive activity and whiteleg shrimp's growth in the nursery phase. Feeding frequency has been reported to cause an increase in shrimp's performance, although it is yet to be clear whether only one or more factors are involved, e.g., feed waste reduction or the reduced degradation of water quality [12].

Despite studies regarding feeding frequency being conducted since the late '90s, for example, the study done by Velasco et al in 1999 [13], no indisputable conclusion has been drawn. Hence, it could be assumed that researchers are still considering the possibility of feeding frequency effect on shrimp's growth. This literature review was conducted to evaluate the effect of feeding frequency management on the growth performance of whiteleg shrimp. The expected output would be the possible recommendation of feeding frequency management that would optimize the growth of whiteleg shrimp in the most efficient way and the most lucrative option for the aquaculture industry.

This study aimed to, i.e., (1) determine the feeding frequency for the most optimal growth of whiteleg shrimp, (2) determine the feeding frequency for the most optimal survival of whiteleg shrimp, (3) determine the feeding frequency for the most optimal FCR (feed conversion ratio) of whiteleg shrimp, and (4) determine the feeding frequency for the most optimal economic return.

2. Research Method

This study is categorized under literature review with the format of semi-systematic review. On a brief note, this literature review was conducted by comparing and analyzing qualitative and quantitative data from the primary literature that has been previously and meticulously shortlisted [14]. Data analysis was conducted with quantitative and descriptive methods.

2.1. Searching and Shortlisting Primary Literature

In the literature review, primary literature is the main component, both as the source of data and as the object of discussion. Therefore, finding and sorting the right primary literature is crucial to produce good literature reviews. Primary literature was searched via Google Scholar and the Elsevier repository with the keywords "vannamei," "feeding" and "frequency", whilst applying Boolean operator "AND" in between every keyword. The search results returned from the repositories were then sorted according to the relevance to the topic at hand, having high credibility, having the required data and parameters, and published in 2005 and onwards.

The process of identification, screening, eligibility, and inclusion in sorting the candidate primary literature was a method provided by the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*). Although the PRISMA was primarily intended for systematic reviews or meta-analyses, it has been extensively used in other literature review formats, especially semi-systematic reviews [15]. Overall, the searching and sorting process of primary literature is provided in the flow diagram in figure 1. Eight primary literature were obtained through the entire sorting process, originating from various journals with credibility index (H Index) of 18, 50, 55, 72, 80, and 164 (four articles from Q1 journals and three articles from Q2 journals), and one article without a Scopus index but was included due to the relevant data and information it contained (Table 1).

2.2. Data Analysis

Data analysis of growth, survival, and FCR of whiteleg shrimp was conducted using MetaInsight application. Significance tests between each feeding frequency treatment were conducted with the Bayesian random effect model method, with credibility of 95% [16]. The eight primary literature have several variations in the experimental variables. Variations in methods include the research period, the culture system used, the protein content in shrimp feed, the stocking density of shrimp in the experimental unit, and the main variable analyzed in this literature study, namely the feeding frequency. The different methods used by each primary literature are important to highlight because they have the potential to bias the analysis results obtained (table 2). Since water quality parameter throughout all primary literature were reported to be within the ideal range for

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shrimp [17] (except for one case explained later in this article), mostly the analysis will neglect the influence of water quality.

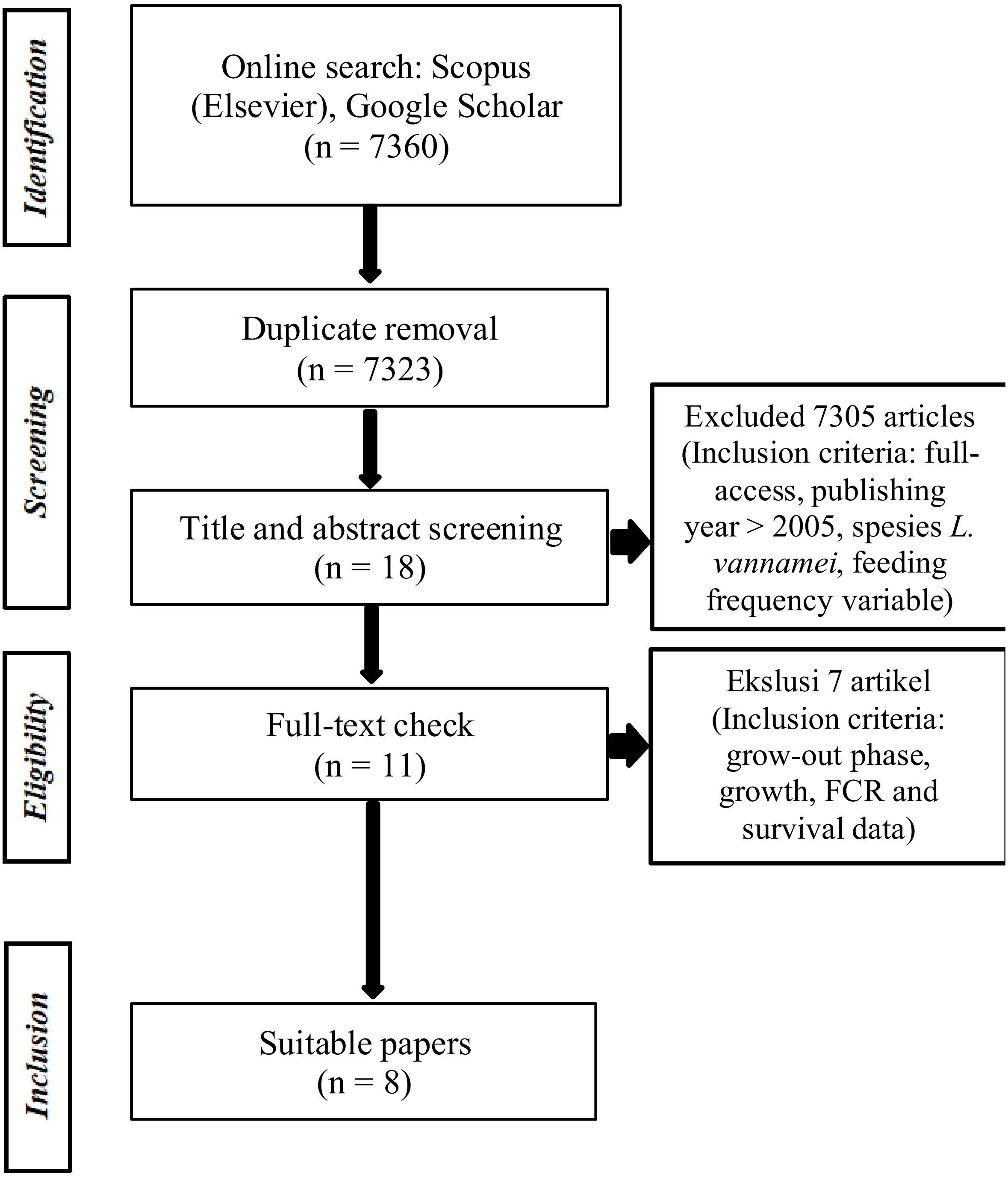

Figure 1 Flow diagram of literature review using PRISMA

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Table 1. List of primary literature

No	Year	Publication	Article Title	Pages	Authors	Journal
1	2020	International Journal, Scopus indexed	Optimizing feed automation: improving timer-feeders and on demand systems in semi-intensive pond culture of shrimp *Litopenaeus vannamei*	Vol. 519, Page 734-759	Reis, J., Novriadi, R., Swanepoel, A., Jing ping, G., Rhodes, M., Davis, D. A.	Aquaculture ISSN: 00448486 **H Index: 164 Q1**
2	2020	International Journal, Scopus indexed	Effects of feeding frequency on growth, feed utilization, digestive enzyme activity and body composition of *Litopenaeus vannamei* in biofloc-based zero-exchange intensive systems	Volume 522, Article number 735079	Wujie Xu, Yu Xu, Haochang Su, Xiaojuan Hu, Yunna Xu, Zhuojia Li,Guoliang Wen, Yucheng Cao	Aquaculture ISSN: 00448486 **H Index: 164 Q1**
3	2019	International Journal, Scopus indexed	The Effect of Dosage Combination and Feeding Frequency on Growth and Survival Rate of v*annamei* Shrimp Juveniles in Ponds	Volume 370, Page 012-033	Zainuddin Z., Aslam yah S., Nur K., Hadijah	IOP Conf. Series: Earth and Environmental Science ISSN: 17551315 **H Index: 18**
4	2019	International Journal, Scopus indexed	Multiple feedings enhance the growth performance and feed efficiency of juvenile *Litopenaeus vannamei* when fed a low-fish meal amino acid-supplemented diet	Volume 27, Issue 2, Pages 337-347	Nunes, A.J.P., Sabry-Neto, H., da Silva, F.H.P., de Oliveira-Neto, A.R., Masagounder, K.	Aquaculture International ISSN: 09676120 **H Index: 50 Q2**
5	2019	International Journal, Scopus indexed	Feed management and the use of automatic feeders in the pond production of Pacific white shrimp *Litopenaeus vannamei*	Volume 50, Issue 1, Pages 54-64	Ullman, C., Rhodes, M., Hanson, T., Cline, D., Davis, D.A	Journal of the World Aquaculture Society ISSN: 17497345 **H Index: 55 Q2**
6	2019	International Journal, Scopus indexed	Effect of feeding frequency on growth and digestive enzyme activity in *Litopenaeus vannamei* during the grow-out phase in biofloc system	Volume 25, Issue 3, Pages 577-584	Nery, R. C., Costa, C.B., Rodrigues, F., Soares, R., Bezerra, R.S., Peixoto, S.	Aquaculture Nutrition ISSN: 13535773 **H Index: 72 Q1**
7	2016	International Journal	Effects of feeding frequency on growth, feed conversion ratio, survival rate and water quality of white leg shrimp (*Litopenaeus vannamei*, Boone, 1931)	Volume 4, Issue 3, Pages 293-297	Mazdak Aalimahmoudi, Alireza Reyshahri, Siamak Salehipour Bavarsad, Milad Maniat	International Journal of Fisheries and Aquatic Studies ISSN: 23475129
8	2006	International Journal, Scopus indexed	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	Volume 252, Issue 2-4, Pages 494-502	Carvalho, E. A., Nunes, A.J.P.	Aquaculture ISSN: 00448486 **H Index: 164 Q1**

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Table 2 Primary literature on variable variations

Literature	Days of culture	Culture system	Feed protein (%)	Stocking density (shrimps m^{-2})	Feeding method	Feeding time range	Feeding frequency (day^{-1})
Reis *et al*. **(2020)**	**91**	*Zero water exchange* (*outdoor*)	**40**	**26**	*On-demand automatic feeding* **dan** *timed automatic feeding*	**7.00 - 19.00**	**36 dan** *on-demand* **(AQ1)**
Xu *et al*. **(2020)**	**56**	*Biofloc-based*, *zero water exchange* **(rumah kaca)**	**40,1**	**300**	*Timed automatic feeding*	**6.00 - 24.00**	**3, 6 dan 12**
Nery *et al*. **(2019)**	**63**	*Biofloc-based* **RAS**	**35**	**150**	*Hand-feeding*	**8.00-16.00**	**1, 2, 3 dan 4**
Zainuddin *et al*. **(2019)**	**56**	*Flow through*	**24,97**	**40**	*Hand-feeding*	**6.00 - 18.00**	**3, 4 dan 5**
Ullman *et al*. **(2019)**	**91**	*Biofloc-based*, *zero water exchange* (*outdoor*)	**40**	**38**	*On-demand automatic feeding, timed automatic feeding* **dan** *hand-feeding*	**8.00 - 19.00**	**2, 6 dan** *on-demand* **(AQ1)**
Nunes *et al*. **(2019)**	**91**	*Flow through* (*outdoor*)	**32**	**100**	*Timed automatic feeding* **dan** *hand-feeding*	**7.30 - 17.30**	**2, 4, 10**
Aalimahmoudi *et al*. **(2016)**	**56**	*Flow through* (*indoor*)	**42**	**57**	*Hand-feeding*	**7.00 - 23.00**	**2, 4 dan 6**
Carvalho & Nunes (2006)	**84**	*Flow through* (*outdoor*)	**40**	**80**	*Hand-feeding*	**7.00 - 17.00**	**2, 3, 4, 5 dan 6**

3. Results and discussion

3.1. Whiteleg Shrimp Growth Performance based on Feeding Frequency

The growth performance of whiteleg shrimp can be assessed through several parameters, including the ones found from the primary literature; growth rate (g/week), survival (%) and feed conversion ratio or FCR. From the eight primary literature, ten values of average growth rates based on feeding frequency were obtained as shown in Figure 2. The feeding frequencies that are applied from the experiments from the primary literature includes one (1x), two (2x), three (3x), four (4x), five (5x), six (6x), ten (10x), twelve (12x) and thirty-six (36x) times per day, and a feeding treatment using on-demand, acoustic automatic feeder (AQ1), where the feed is automatically discharged into the shrimps only if there is feeding stimulus from the shrimps.

The lowest growth rate was found in the 1x treatment, with a growth rate of 0.62 ± 0.47 g/week. The growth rate of the shrimps increased to 0.87 ± 0.35 g/week at 2x feeding frequency and then reached 0.97 ± 0.47 g/week at 3x feeding

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frequency before plummeting down to 0.7 ± 0.19 g/week and 0.63 ± 0.29 g/week at 4x and 5x feeding frequencies, respectively. The growth rate then saw an increase up to 1.36 ± 0.48 g/week at 6x feeding frequency but dropped drastically to 0.88 ± 0.06 g/week at 10x feeding frequency. From this point, increase in feeding frequency was followed by an increase in the growth rate as well; at 12x and 36x feeding frequencies, the growth rate was at 1.85 ± 0.08 g/week and 1.97 ± 0.19 g/week, respectively. The final treatment, the on-demand acoustic automatic feeder (AQ1), produced the highest growth rate of 2.46 ± 0.15 g/week.

In using the Bayesian random-effect model, one treatment is treated as a "control" which will be used as the main comparison against other treatments. In this analysis, treatment of 4x feeding frequency was used as a control because it is a common feeding frequency used in aquaculture industry practice [17]. Based on Figure 3, the results of statistical inference show that of all the feeding frequency treatments, only the AQ1 treatment has a significant effect ($P < 0.05$), indicated by the range of the credible interval (CrI) line which inside the range of 0.415 - 1.07 (marked in green) and does not intersect the x = 0 line or line-of-no-effect. The 1x to 36x treatments have a credible interval (CrI) line span that crosses the line-of-no-effect. This indicates that there is no significant influence.

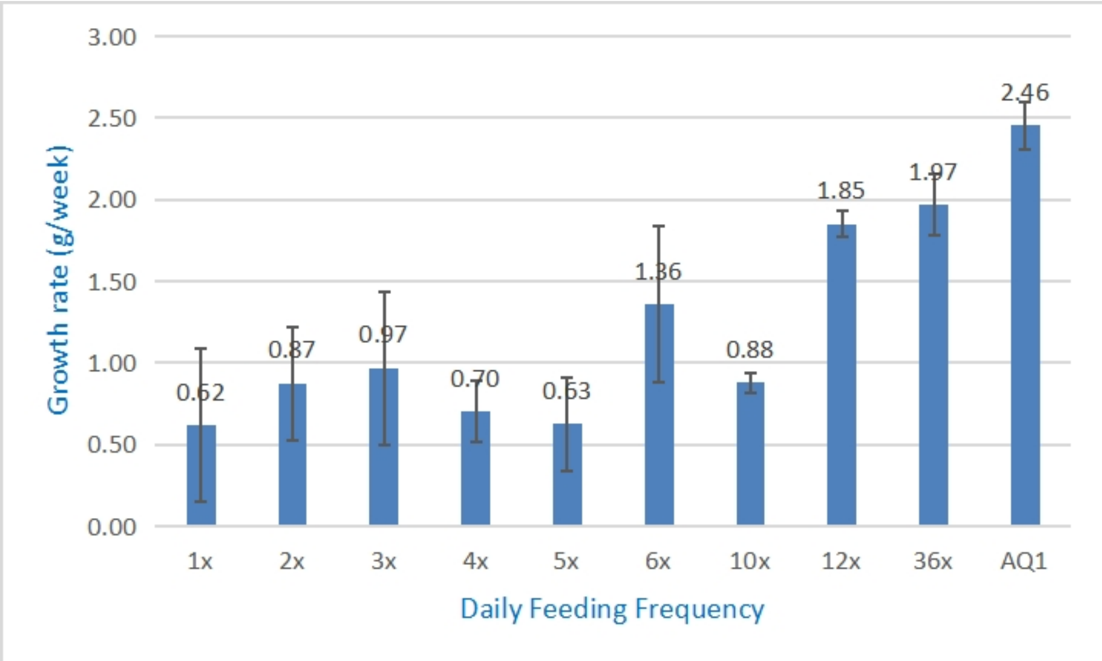

Figure 2 Growth rate based on feeding frequency

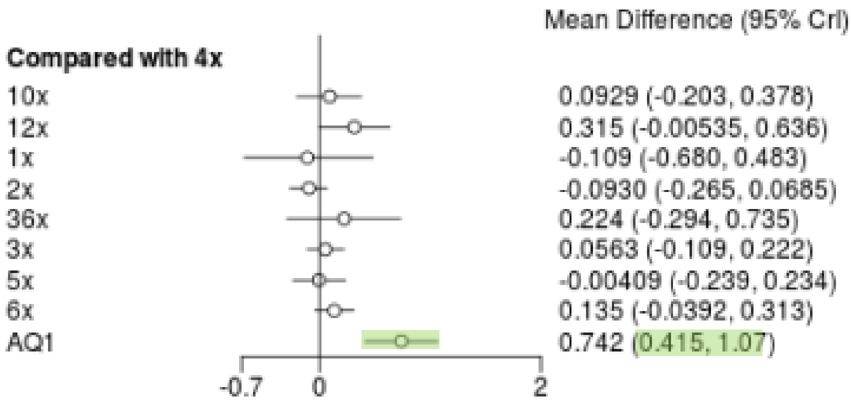

Figure 3 Forest plot of growth rate based on feeding frequency

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Based on Figure 4, the lowest shrimp survival rate is found in on-demand feeding (AQ1), which is 72.61 ± 14.74%. The survival rate from treatments 1x to 5x show no significant difference, with values of 78.3 ± 1.3%, 76.15 ± 10.61%; 76.69 ± 14.41%, 79.72 ± 12.38% and 80.84 ± 6.96%, respectively. Then, at the 6x feeding frequency, the survival rate decreased to 74.9 ± 17.67%. At 10x feeding, the highest survival rate was 94.24 ± 6.1%, then it decreased slightly to 90.15 ± 1.77% at a feeding frequency of 12x. The subsequent addition of the feeding frequency at 36x and AQ1 on-demand system resulted in a drastic reduction in survival rates of 77.6 ± 13.04% and 72.61 ± 14.74, respectively.

Based on the Forest plot in Figure 5, there was no significant difference in the frequency of feeding on the survival rate of white shrimp (P> 0.05). This is indicated by the range of the credible line intervals in each treatment that intersects the line-of-no-effect. However, the statistical inference is not too conclusive. The overall credible interval for survival data is relatively wide, with the widest interval found in the 36x treatment (-44.0, 30.4), which reduces the reliability of the inference.

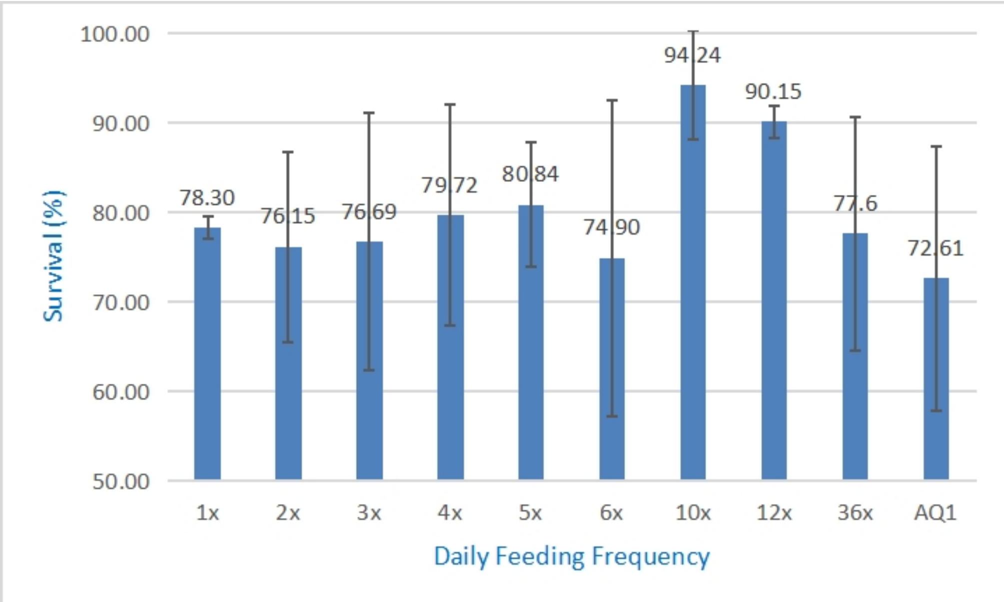

Figure 4 Survival based on feeding frequency

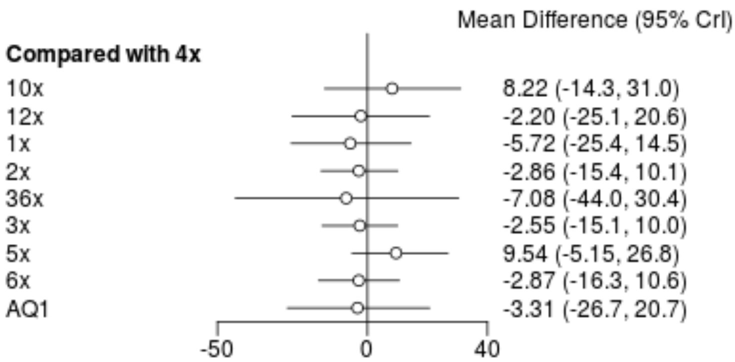

Figure 5 Forest plot of survival based on feeding frequency

The feed conversion ratio (FCR) between treatments of feeding frequency can be seen in Figure 6. Treatment 1x gives an FCR of 1.71, followed by a decrease in the efficiency of feed use in treatment 2x, with an FCR of 2.08, and then a further decrease to 1.95 on treatment 3x before spiking to the highest FCR of 2.30 at treatment 4x. Furthermore, along with the increase in feeding frequency, the FCR decreased, from 1.98 in treatment 5x to 1.83, 1.74, 1.19 then reaches the lowest point or the most efficient use of feed in treatment 36x with an FCR of 0.99. In treatment

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AQ1, the use of feed was still classified as very efficient, with an FCR of 1.11.

Although the inter-treatment FCR data showed quite a contrast, especially the FCR of treatments 12x, 36x, and AQ1 compared to other treatments, the statistical inference did not show a significant difference (P> 0.05). It can be seen from the Forest plot in Figure 7 that none of the treatments' credible intervals intersect nor cross the line-of-zero-effect. Similar to the Forest plot results for survival data, the overall credible interval range in the FCR Forest plot data is still too wide to provide reliable inference. The reason being is that the FCR at 36x treatment (0.99) is very far compared to 4x treatment or control treatment (2.3), but there was no significant difference from statistical analysis.

However, the credible interval at 36x treatment is still too wide (-1.48, 1.56) to conclude. In short, for the time being, the initial hypothesis regarding the effect of feeding frequency on FCR was rejected because the statistical analysis did not show any significant difference. If the analysis was to be carried out with a larger sample and with low heterogeneity, it would be possible to see a significant difference, especially in the 36x, AQ1, and 12x treatments, where the FCR difference was visible compared to the 4x treatment.

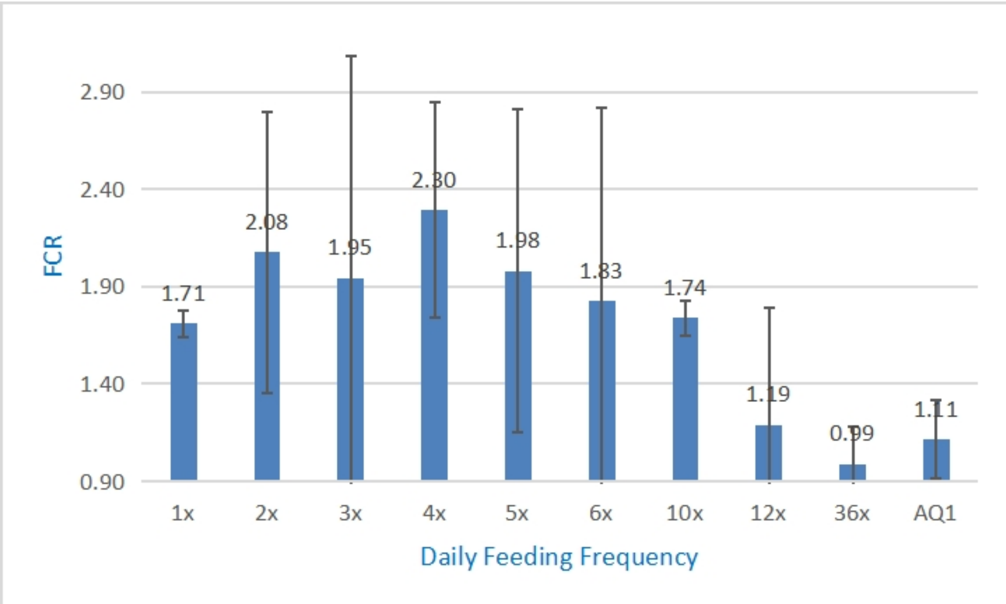

Figure 6 FCR based on feeding frequency

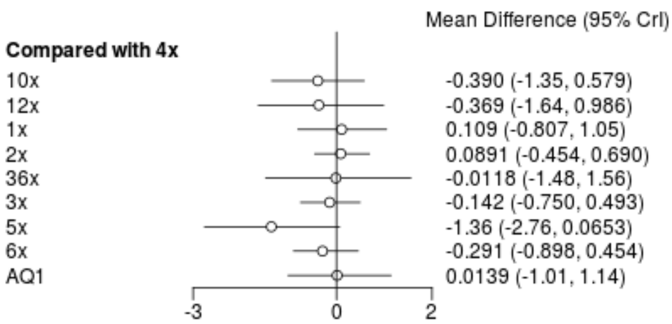

Figure 7 Forest plot of FCR based on feeding frequency

3.2. Feeding Frequency's Relation to Whiteleg Shrimps' Endogenous Factors

Most organisms exhibit biological rhythms, which are adaptive strategies, for them to adapt certain physiological processes to occur at the most favorable moments [18]. The dark/light cycle is one of the environmental factors that most influence the formation of biological rhythms of organisms. Biological components generate these rhythms called pacemakers, which consistently express the pattern of origin even though the organism has been isolated from environmental influences [19].

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The experiment conducted by Santos et al. [20] was based on the premise that white shrimp also have an endogenous circadian rhythm that is influenced by the light/dark cycle. After being observed, the endogenous rhythm of shrimp is that they tend to be more active in the dark phase or at night after 19:00, or in other words, they are nocturnal animals. The percentage of locomotion and feeding activities conducted in a day was 67.7 ± 2.5% and 81.9 ± 2.3% of those activities were performed at night.

As evidence that feeding activity on white shrimp is more effective at night, Santos et al. [20] measured the amount of feed consumed during daytime and nighttime. It can be seen from the graph that the total daily feed intake at night was 1.1 ± 0.2 g/day in the dark phase compared to 0.2 ± 0.1 g/day in the light phase. Based on these findings, it was concluded that in the endogenous rhythm of white shrimp, most of the feeding activity occurs at night.

Another finding regarding the feeding rhythm of white shrimp was reported by Hernandez-Cortes et al. [21], where white shrimp were fed once every 2 hours for 5 days to see the pattern of feed consumption in a day. For 5 days a consistent pattern was found, the peak of feed consumption by white shrimp occurred from 20.00 to 24.00. Within this range, the amount of feed consumed reached 30.4% of the daily intake.

If we review the eight primary literature, it can be seen that the feeding schedule which includes the dark phase (6:00 to 24:00) results in a higher growth rate when compared to the feeding schedule which only covers the light phase (6:00 to 18:00). Based on the illustration of the feeding schedule applied by the eight primary literature (Figure 8), shrimp fed until the dark phase produced a minimum growth of 0.65 g/week which was obtained from treatment 2x by Aalimahmoudi et al. [22] and a maximum of 2.49 g/week from the AQ1 treatment by Reis et al. [23]. On the other hand, shrimp fed only during the light phase showed a low growth rate with a minimum value of 0.44 g/week from treatment 3x by Zainuddin et al. [24] and a maximum value of 0.91 g/week from treatment 3x by Carvalho & Nunes [25].

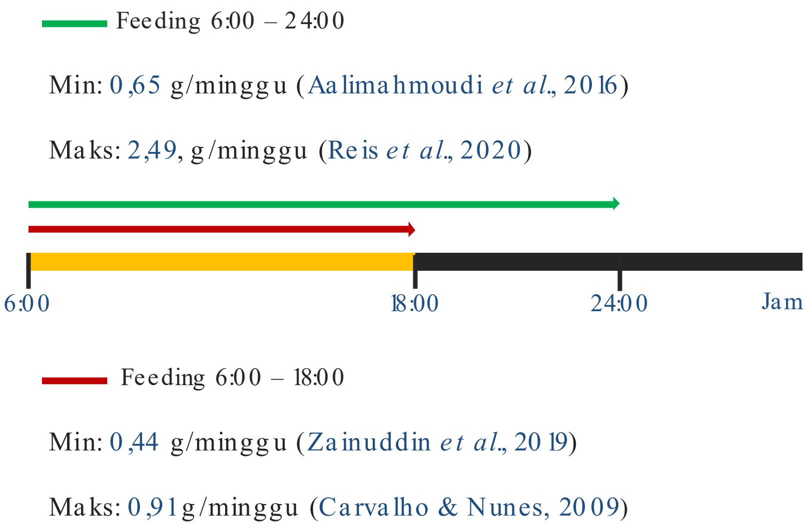

Figure 8 Growth rate comparison of with and without dark phase feeding

This phenomenon correlates with the findings of Hernandez-Cortes et al. [18] and Santos et al. [20] who showed that most of the feeding activities of white shrimp occur at night. Feeding only in the light phase is not following the endogenous rhythm of feeding white shrimp, hence the literature that applied that feeding schedule lacks optimal shrimp growth. The feeding schedule does not, however, appear to produce a strong effect on the survival rate and FCR data. According to these findings, it can be concluded that to optimize the growth rate of white shrimp, the feeding schedule must include the peak period of white shrimp feeding activity, which is around 20:00 to 24:00.

The experiment of Xu et al. [26] reported that feeding frequency affects the activity of digestive enzymes, specifically proteases, carbohydrases, and lipases. As the feeding frequency increased from 3 times, 6 times to 12 times a day, there was a significant increase in proteases in the stomach. The increase in enzymatic activity will certainly increase the effectiveness of digestion and absorption of nutrients, which are the basic ingredients for growth, showed by the increase in the growth rate of the feeding treatment 3 times to 12 times per day [26].

It is also worth mentioning that FCR is also influenced by increased enzymatic activity, as observed by Xu et al. [26], where the FCR decreased from 1.39; 1.30 to 1.19 at feeding frequencies of 3, 6, and 12 times/day, respectively. The main

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FCR data (Figure 6) also displays a trend of FCR decline from 4x to 36x treatment. Thus, it can be concluded that the optimization of growth rate and FCR can be done by increasing enzymatic activity to increase nutrient absorption by increasing the feeding frequency to 36x or by applying an on-demand system (AQ1).

3.3. *Relation between Whiteleg Shrimps' Exogenous Factors and Feeding Frequency*

At a glance, DO parameters from all analyzed literature fall into the DO range that is adequate for shrimp needs, ranging from 4 mg/L to 6.9 mg/L. However, treatment AQ1 from one of the primary literature [27] reported an acute drop in DO (<3 mg/L) occurring about 25 times per examination in the early morning. Lack of data and explanations for how long DO values last throughout the night before being checked in the morning makes it difficult to draw definitive conclusions regarding the effect of the low DO. The authors mentioned that one repetition of the AQ1 treatment had to be discontinued at week 11 because they DO levels reached lethal levels and the mortality rate was too high. According to Cheng et al. [28], hypoxia or sub-optimal DO levels in water (1 - 5 mg/L) will inhibit shrimp growth because feeding behavior and feed-to-meat conversion efficiency are not as intense as under normal DO conditions. Hypoxia is reported to reduce the total haemocyte count (THC) which elevates shrimps' sensitivity and susceptibility to various types of pathogens [28].

Apart from DO, a contrasting temperature parameter discrepancy is found in one of the primary literature. The experiment by Nery et al. [29] took the second-lowest position with a growth rate of 0.57 g/week. When compared with other experiments, this discrepancy could be caused by several factors such as the location of the culture pond which was located indoors, and the culture water temperature which averaged 24.8 ± 0.7 °C throughout the experiment, while the water temperature of other experiments ranged from 27.69 °C [25] up to 30.2 ± 1 °C [30]. These findings are important to highlight because, according to Wyban et al. [31], the growth performance of *L. vannamei* is very sensitive to small changes in temperature. In addition, the optimal temperature (the temperature that produces the best growth) of *L. vannamei* is size-specific, where the optimal temperature for small size (<5 g) is around 30 °C, and for larger shrimp it is between 27 °C, whereas 23 °C was rated as sub-optimal for all shrimp sizes [31]. If Nery et al. [29] optimized the temperature parameter in the experiment, an increase in shrimp growth performance can be predicted.

Experiments by Zainuddin et al. [24] occupied the lowest position, with a growth rate of only 0.44 g / week. This phenomenon may be related to the low levels of crude protein (CP) in the feed used in the experiment. All primary literature except Zainuddin et al. [24] applied pellet feeds with CP levels ranging from 32% to 40%. In fact, according to Lee & Lee [32], the optimal CP levels for whiteleg shrimp growth in juvenile, sub-adult, and adult phases were 34.5%, 35.6%, and 32.2%, respectively.

Feed leaching is the phenomenon where the nutritional content of the feed dissolves and dissipates into the water due to being submerged for too long. According to Carvalho & Nunes [25], the loss of CP content from feed leaching peaks between two and three hours after the feed is submerged, reaching a maximum of 6.91%. Despite this, findings by Smith et al. [33] showed that the loss of CP of 15% after submerging the feed for 4 hours had no significant impact on growth. Moreover, the effect of feed leaching was expected to be more pronounced under more culture-intensive conditions, where there are no flocs or natural food sources present [25].

In retrospect, the trend in FCR shown in Figure 6 is decreasing trend as the frequency of feeding increases, especially after treatment 4x. The decrease in FCR or the increase in feed efficiency is thought to be influenced by the increase in the consumption of relatively fresh feed due to reduced feed leaching during this short feeding period [34]. The reason is, in the treatment of low feeding frequency such as 1x to 4x, the percentage daily feed portion given at each feeding time is more than that of the high feeding frequency treatments. For example, in the 1x treatment because the feeding is only once, the feeding covers 100% of the total daily portion, then for the 2x treatment because the feeding is done twice, each provision amounts to 50% of the total daily portion, and so on. The implication is that at lower feeding frequencies, the shrimp will leave a lot of uneaten feed, which will eventually be lost through leaching because it only has a limited capacity to digest food in the first hour [35]. This has been shown to increase FCR and also slow down the growth rate. Meanwhile, by dividing the portion into smaller feeds that are more frequent according to the GPT of white shrimp, the FCR and growth rate will be optimized.

The culture system certainly has a positive impact on the growth performance of white shrimp, in this case in terms of food supply. For example, in the 6x feeding frequency treatment, the culture system in the experiment of Xu et al. [26] is a biofloc, so even though the interval between feeding is quite long, shrimp have an alternative source of food in the form of flocs to compensate the nutritional needs. In the treatment of the same feeding frequency, Aalimahmoudi et al. [22] implemented feeding at 3-hour intervals. This is because the culture system applied is not biofloc but flow-through and water quality control is carried out by changing the water by as much as 20% per day. The implication is that the impact of feed leaching is more visible because there is no alternative feed source [25]. As a result, the absorption of feed nutrients in shrimp in the experiment of Aalimahmoudi

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et al. [22] was not optimal and the growth rate was affected (0.88 g/week), compared to Xu et al. [26] which resulted in a growth rate of 1.67 g/week (Figure 9). Experiments by Ullman et al. [27] also use a biofloc system based on zero water discharge, and the growth rate can reach 1.89 g/week. This is different from Carvalho & Nunes [25] in which a conventional flow-through system was applied.

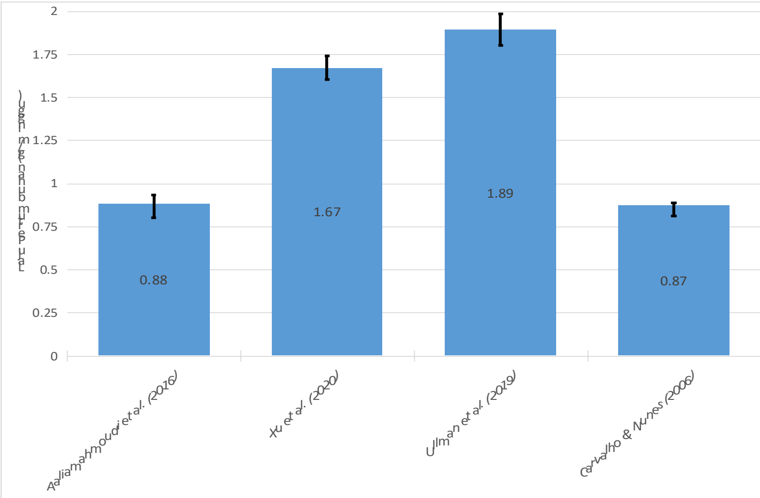

Figure 9 Growth rate of treatment 6x

Tacon et al. [9] reported that ponds undergo rapid development of microbial food chains, starting from the growth of autotrophic microbial communities characterized by the appearance of a greenish color in the water. It then turns into heterotrophic communities that appear in the water in the form of suspended particles or "floc". The composition of the floc is reported to include bacteria, algae, diatoms, flagellates, ciliates, amoebae, rotifers, nematodes, and gastrotrich. Some findings by Moss et al. [36] stated that the organisms in the floc were not only an alternative source of nutrition but also had a positive impact on enzyme activity and the microbiome of the digestive tract of shrimp. In addition, the stomach is the first digestive organ to pass by food after the mouth, so the production and secretion of enzymes by biofloc microorganisms may contribute to the increased activity of protease and amylase enzymes in the stomach [29, 37]. Thus, it can be concluded that the biofloc culture system can optimize the overall growth performance of shrimp.

3.4. Optimizing Feeding Frequency

Overall AQ1 treatment is the best feeding system because it not only adjusts the best feeding frequency for shrimp but also the amount of feed. Bador et al. [38] found that in considering both endogenous factors (circadian rhythm, molting, etc.) As well as exogenous factors (temperature, salinity, etc.), fluctuations in the amount of feed consumption were observed. Therefore, applying fixed feeding frequency and feed portions throughout the entire cycle of production potentially jeopardizes the growth rate, survival, and FCR of shrimps. The on-demand system guarantees the best feed efficiency without having to perform difficult calculations by relying on acoustic sensors, especially in the involvement of endogenous and exogenous factors that are difficult to control. If a simulation of whiteleg shrimp production is carried out for one cycle (90 days) at a stocking density of 100 individuals/m2 by considering the parameters of growth rate, survival rate, and FCR of all feeding frequency treatment, the projected gross profit (only feed cost deduction) can be seen in Table 3.

Based on these projection results, the most profitable production is yielded by treatment AQ1, with a gross profit of Rp. 133,563,737 per unit area of 0.1 ha. Although the additional costs of the AQ1 feeder and sensor equipment have not been accounted for (around Rp. 6 million per unit), 0.1 ha of pond area only requires 1 unit, so the resulting profit remains superior. The valuation of shrimp produced by AQ1 treatment is very high because the shrimp prices in the market are not equal for all sizes, but each size has its price (the latest shrimp size prices can be seen on the app.jala.tech page). For example, shrimp harvested at 10 g would be priced at Rp. 51,000 per kilogram, whereas at 11 g it would be priced at Rp. 52,000 and at 12.5 g it would be priced at Rp. 55,000. For the size of the shrimp harvest produced by the AQ1 treatment (31.57 g), the market is valued at Rp. 85,000 per kilogram. Therefore, although AQ1 treatment shows the lowest survival parameter (72.61%), on a larger scale it produces the largest profit.

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Table 3 Projection of gross profit based on feeding frequency treatments

Treatment	Final weight (kg)	Total feed (kg/0,1 ha)	Biomass (kg/0,1 ha)	Price (kg^{-1})	Yield value (0,1 ha^{-1})	Gross profit (0,1 ha^{-1})
1x	7.97	1067	624	Rp44,000	Rp27,463,166	Rp1,847,522
2x	11.24	1778	856	Rp52,000	Rp44,518,489	Rp1,838,271
3x	12.46	1859	956	Rp55,000	Rp52,562,602	Rp7,951,288
4x	9.04	1654	720	Rp49,000	Rp35,302,966	-Rp4,392,553
5x	8.04	1286	650	Rp44,000	Rp28,580,946	-Rp2,286,476
6x	17.46	2388	1308	Rp63,000	Rp82,384,102	Rp25,076,151
10x	11.31	1855	1066	Rp52,000	Rp55,445,431	Rp10,918,485
12x	23.79	2552	2144	Rp77,000	Rp165,109,725	Rp103,869,027
36x	25.33	1946	1965	Rp77,000	Rp151,343,280	Rp104,643,068
AQ1	31.57	2555	2293	Rp85,000	Rp194,877,123	Rp133,563,737

4. Conclusion

Based on the discussion that has been carried out, several conclusions can be drawn from this literature review: (1) the most optimal feeding frequency (P <0.05) for the growth rate of whiteleg shrimp (*L. vannamei*) is feeding with the on-demand system (AQ1), (2) the feeding frequency did not have a statistically significant effect on the survival of whiteleg shrimp (*L. vannamei*) (P> 0.05), (3) the feeding frequency did not have a statistically significant effect on shrimp FCR (*L. vannamei*) (P> 0.05), and (4) the most optimal feeding frequency for white shrimp production on an industrial scale is the on-demand system (AQ1).

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