The effect of feeding rate on the growth and BCR in TGGG hybrid grouper (♀ tiger grouper × ♂ giant grouper) cultivation

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Abstract. This research examined the feeding rate optimization in TGGG (♀ tiger grouper × ♂ giant grouper) hybrid grouper cultivation. Feeding optimization is pivotal for cost efficiency in fish farming. This experimental research was conducted for 30 days using TGGG hybrid grouper fingerlings with an average size of 24.76 g (±1.67 g). Different feeding rates were applied in the treatments (4% fish biomass per day in treatment A, 5% in treatment B, and 6% in treatment C) with 2 repetitions of each treatment. Treatment A showed the best outcomes with the highest growth (WGR 38.0% and SGR 1.04% day^{-1}), the most efficient FCR (i.e 3.69) and the highest BCR (i.e 1.08). To conclude, the optimal feeding rates include 4.10% fish biomass per day for BCR, 4.19% fish biomass per day for FCR, and 4.23% fish biomass per day for both WGR and SGR.
Key Words: BCR, FCR, feeding rate, SGR, WGR.

Introduction. Feeding optimization is important for cost efficiency in intensive fish farming, where feeding cost has the largest proportion (Gao et al 2022; Wijayanto et al 2022), including in TGGG hybrid grouper (♀ tiger grouper, *Epinephelus fuscoguttatus* × ♂ giant grouper, *E. lanceolatus*) cultivation. El-Sayed et al (2015) estimated that the cost of feed could reach 75 to 90% of the whole operational costs. Efficiency to the feed cost can be performed by replacing raw materials as a substitute for protein sources, most of which use fish meal (Boonyaratpalin et al 1998; El-Sayed 1999). Alternatively, fish farmers can opt for feeding rate optimization. In regards to these concerns, this study was performed to examine the feeding rate in TGGG hybrid grouper aquaculture in terms of cost efficiency and profit optimization. Waste of feed will lead to a decrease in profits, while the remnants also decrease the quality of the cultivation media (Wijayanto et al 2022).

TGGG hybrid grouper cultivation has been developed in Indonesia since 2017 with major focus on growth acceleration and body resistance enhancement (Wijayanto et al 2023a, b). Tiger grouper and humpback grouper (*Cromileptes altivelis*) were more preferred before the presence of TGGG hybrid grouper. Faster growth rate in fish leads to faster capital turnover (Myoung et al 2013; Koh et al 2016; Bulanin et al 2017; Chieng et al 2018; Fadli et al 2022). This research examined the effect of feeding rate on growth, feed efficiency and profit in TGGG hybrid grouper cultivation.

Material and Method

Location and time of research. This experiment was conducted for 30 days, from February to March 2023 at the Laboratory of the Faculty of Fisheries and Marine Sciences, Universitas Diponegoro (Figure 1).

Figure 1. Research location.

Fish seedling. The TGGG hybrid grouper fingerlings used in this research had an average size of 24.76 g (±1.67 g).

Test feed. The test fish were fed commercial feed with a minimum crude protein content of 46%. Different feeding treatments were applied; 4% biomass in treatment A, 5% in treatment B, and 6% in treatment C. Each treatment was replicated twice using completely randomized design (use 6 tanks). Feeding was done in the morning, afternoon, and evening.

Fish rearing media. A total of 84 test fish were reared in tanks with a volume of 0.4 m^3 of water (100 x 100 x 40 cm) with 14 fish per tank. The fish seeds were gained from marine fish hatcheries in Situbondo Regency (565 km from Semarang City) and had been first adapted a water medium salinity of 5 ppt in the laboratory. To prepare for the research, the initial water salinity of 34 ppt was gradually reduced to 5 ppt in 30 days.

Water recirculation. Water quality was maintained using a recirculation system through filters consisting of cloth, dacron, gravel and commercial bioballs. Fish waste was cleaned daily, and 10% of the water was changed every 10 days. Water quality parameters that included dissolved oxygen (DO), pH, salinity, and temperature were examined every 10 days using Horiba U-50.

Data analysis. Data on the progress of fish weight were collected every 10 days. The variables examined in this study that included fish growth (i.e weight gain rate (WGR) and specific growth rate (SGR)), survival rate (SR), feed convertion ratio (FCR), and benefit cost ratio (BCR) were measured using the following formulas (Norazmi-Lokman et al 2020; Long et al 2022; Wijayanto et al 2023a, b):

$$WGR = (Wt - Wo)/Wo \quad [1]$$

$$SGR = [(Ln\ Wt - Ln\ Wo)/t] \times 100 \quad [2]$$

$$FCR = F/W \quad [3]$$

$$SR = Nt/No \quad [4]$$

$$BCR = B/C \quad [5]$$

The WGR for TGGG grouper is expressed in percent, calculated using the final grouper weight (Wt in grams) and the initial TGGG grouper weight (Wo in grams). The SGR for TGGG grouper is also expressed as a percentage (% day^{-1}). The natural logarithm (Ln) was utilized in these calculations. The t is the experimental days. The FCR represents the amount of feed (F in grams) required to increase fish weight (W in grams). The SR, measured in percentage (%), indicates grouper's survival success. The final and initial numbers of TGGG grouper (Nt and No, respectively) were compared. Futhermore, the BCR took into account the additional revenue due to TGGG grouper growth (B in IDR) and the cost of feed (C in IDR). Statistical analysis in the forms of Anova and Duncan tests were employed to statistically analyze the impact of treatment, while optimization modeling was created by equating the first derivative procedure to zero.

Results. The water salinity of 5 ppt was used. Reducing salinity from 34 ppt to 5 ppt did not reduce the fish's appetite. This condition indicated that TGGG hybrid grouper could be reared on low salinity media, opening up the opportunity for fish farmers who live far from the coast to cultivate this fish which has high economic value. Research on the cultivation of the TGGG hybrid grouper at low salinity has been conducted with an optimal salinity of 7-8 ppt (Wijayanto et al 2023a, b). Detailed research results are presented in Table 1 (WGR, SGR, SR, FCR and BCR) and Figure 2 (fish growth). In general, treatment A showed the best outcomes with the highest WGR, SGR and BCR, and the most efficient FCR.

Table 1

WGR, SGR, SR, FCR and BCR of TGGG hybrid grouper

Variable	*A1*	*A2*	*B1*	*B2*	*C1*	*C2*
W_o (g ind^{-1})	25.83	25.82	25.86	25.85	25.84	25.84
W_t (g ind^{-1})	36.13	35.14	33.81	36.36	32.73	31.79
N_o (ind)	14	14	14	14	14	14
N_t (ind)	14	14	14	14	14	14
WGR (%)	39.9%	36.1%	30.7%	40.7%	26.7%	23.0%
SGR (% day^{-1})	1.08%	0.99%	0.86%	1.10%	0.76%	0.67%
SR (%)	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
FCR	3.52	3.84	4.54	3.53	5.17	5.88
BCR	1.12	1.03	0.87	1.12	0.76	0.67

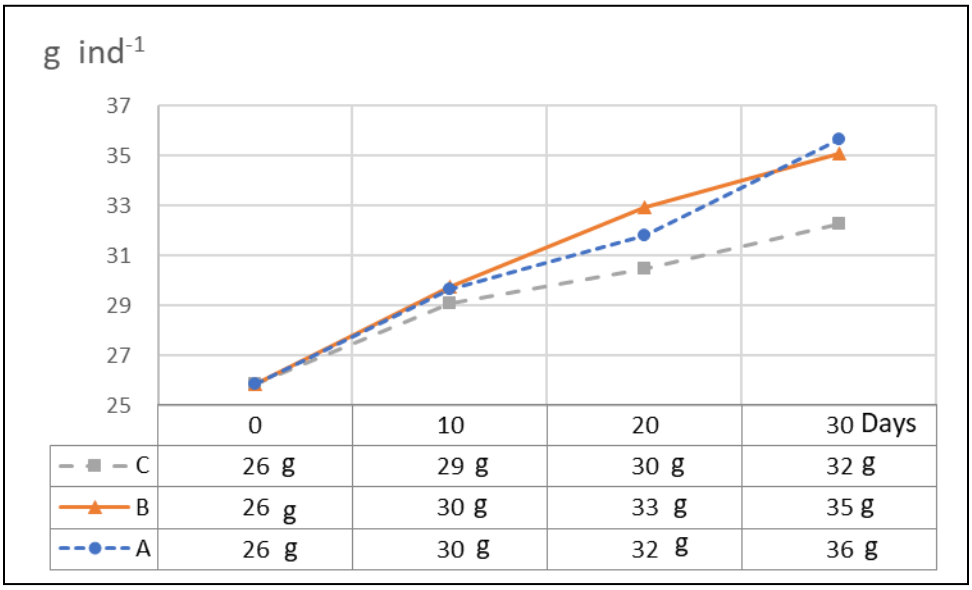

Figure 2. The average of fish growth progress.

At the beginning of the experiment, the average fish weight between of the fish was relatively equal. As the fish matured, fish in treatments A and B had higher growth compared to treatment C. Treatment A showed the least remnants. In treatments B and C, some of the fish feed was not eaten, while treatment C left the most remnants. Fish feed remnants can cause more turbid air tests, requiring extra siphon processes in treatment C. The results indicated that feeding needs to be done at the right dose since overfeeding leads to cost inefficiencies and lower water quality.

The average of FCR in treatment A was 3.69, implying that 1 gram of weight increase requires 3.69 grams of feed (as outlined in Table 2). Conversely, the BCR for treatment A stood at 1.08, implying that an incremental expenditure of IDR 1 yielded an additional income of IDR 1.08. The SR remained consistent at 100% across all treatments. The results of the statistical analysis are presented in Table 2, while Figure 3 (feeding rate relationship with WGR, SGR, FCR and BCR) and Table 3 (optimal feeding rate estimation) show the visual representation of the optimization process. WGR, SGR, SR, and BCR exhibited no statistically significant deviations at a significance level of α = 5%. A notable disparity was observed in FCR, particularly between treatments A and C, as evidenced by the results of Duncan's test. It is plausible that extending the experimental duration might unveil more pronounced differences in outcomes.

Table 2

Statistical analysis

Variable	*Average value*			*F value*	*Sig value*	*Note**
	A	*B*	*C*			
WGR (%)	38.0	35.7	24.8	4.662	0.210	Not significant
SGR (% day^{-1})	1.04	0.98	0.72	4.905	0.113	Not significant
SR (%)	100.0	100.0	100.0	Unidentified	Unidentified	Not significant
FCR	3.69	4.04	5.53	7.034	0.074	Significant: $A^{a} < B^{a,b} < C^{b,c}$
BCR	1.08	1.00	0.72	5.265	0.104	Not significant

Note: *at α = 5%. The notations a, b and c denote subsets.

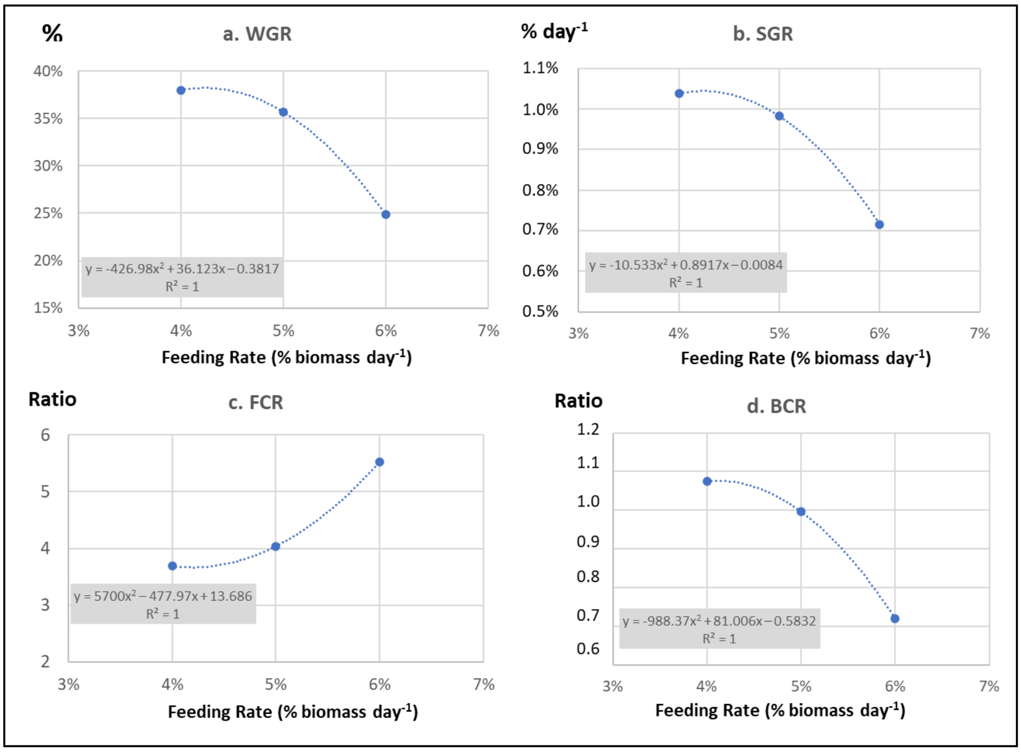

Figure 2. Modeling of treatment optimization of WGR, SGR, FCR and BCR.

Table 3

Optimal treatment estimation

Variable	*Optimal feeding rate (% biomass day^{-1})*	*Variable value estimation*
WGR	4.23%	38.2%
SGR	4.23%	1.05% day^{-1}
FCR	4.19%	3.666
BCR	4.10%	1.077

The optimal feeding was identified between 4.1 and 4.23% of fish biomass per day, which percentages were closer to treatment A. Excessive feeding reduces the fish farming success. The parameters of water quality observed during this experiment are shown in Table 4.

Table 4

Water quality during research

Parameters	A_1	A_2	B_1	B_2	C_1	C_2
pH	7.4±0.49	7.6±0.31	7.7±0.25	7.6±0.38	7.6±0.35	7.6±0.29
DO (ppm)	6.1±0.29	6.2±0.23	5.9±0.30	6.3±0.21	5.8±0.21	5.6±0.20
Temperature (°C)	24.3±0.76	24.2±0.59	24.2±0.67	24.1±0.61	24.0±0.65	24.0±0.66
Initial salinity (ppt)	34±0	34±0	34±0	34±0	34±0	34±0
Final salinity (ppt)	5±0	5±0	5±0	5±0	5±0	5±0

The water quality in the fish tanks was regarded ideal for the growth and survival of the TGGG hybrid grouper, especially the pH and DO levels. The optimal temperature for TGGG grouper fish ranges between 29 and 30°C, pH between 6.5 and 8.5, and DO of more than 5 ppm (Herry et al 2019). The temperature at the time of the experiment was around 24°C because the experiment was carried out in an indoor laboratory in tropical climate area. Regardless the lower temperature, the appetite of the test fish remained strong.

Discussion. Grouper fish is one of the main fish commodities in Indonesia. The grouper aquaculture production in Indonesia in 2020 reached to 9,478 tons, with cultivation locations spread across various islands including Sumatra, Java, West Nusa Tenggara, East Nusa Tenggara, Maluku, and Bali (DJPB 2017; KKP 2020, 2022). However, several species of grouper fish are under the threat of extinction. The giant grouper and tiger grouper are listed on the IUCN Red List of Threatened Species with a vulnerable status (Fennessy et al 2018; Rhodes et al 2018). Therefore, grouper cultivation is also expected to reduce grouper exploitation in nature.

In this research, 5 ppt water salinity did not cause a decrease in fish appetite despite the optimal level is between 7 and 8 ppt (Wijayanto et al 2023a, b). This finding appears as a promising opportunity for TGGG hybrid grouper farming in locations away from the coast. Fish farmers in Indonesia who live far from the coast usually raise tilapia, catfish, carp with prices below USD 1.9 kg^{-1}. TTGG hybrid grouper offers higher economic value of around USD 6.34 kg^{-1} (Wijayanto et al 2022, 2023a, b). TGGG hybrid grouper from Indonesia has been exported to Hong Kong, Malaysia, Singapore, Taiwan, China, and Japan (DJPB 2017).

The success of intensive aquaculture is determined by the feeding method (Wijayanto et al 2022). Fish need adequate nutritional intake in terms of both quantity and quality. Therefore, the amount of artificial feed needs to be optimally adjusted to the specific need. Insufficient amount of fish feed can inhibit fish growth and reduce fish resistance to various diseases. On the other side, excessive feeding will cause inefficiency and reduce water quality (Craig & Helfrich 2009; Wijayanto et al 2022). Commercial feed and trash fish have been used as feed to stimulate the growth of TGGG hybrid grouper. Commercial feed manufacturers have developed grouper feeds that contain certain nutrients that fish need, including protein, carbohydrates, fats, vitamins, and minerals. However, the price of this feed is relatively expensive, thereby efforts have been made to produce alternative feeds that have equally high protein content. Several researchers have tried to use other ingredients such as soybean (Boonyaratpalin et al 1998). El-Sayed et al (2015) recommended using local raw materials in fish feed for better efficiency while maintaining the quality of fish feed at the same time. Aldon (1997) suggested that the composition of the feed should be close to the composition of the meat of the fish being reared. Producing ideal artificial fish feed is challenging for fish farmers. Hence, for practical purpose, fish farmers in Indonesia prefer manufactured commercial fish feed.

Optimal feeding frequency is also significant to guarantee healthy, high-quality, sustainable, and economical fish harvest (Norazmi-Lokman et al 2020). Efficient feeding program should be applied to gain better growth (da Cunha et al 2013). Optimal feeding frequency may vary depending on fish species, fish size and culture media conditions (Gao et al 2022). In this research, feeding was carried out 3 times a day in the morning, afternoon, and evening. In this experiment, the fish showed stronger appetite in the morning and evening than during the day. Silva et al (2022) explained that groupers are more active at night (nocturnal). As the results, the appetite during the day is lower than in the morning and evening.

Treatment A obtained the highest average growth (WGR and SGR), the most efficient FCR, and the highest BCR. These findings hold significant implications for optimizing feeding practices. While certain fish farmers rely on subjective assessments of fish preferences when providing feed - often following an ad libitum approach - such an approach proves challenging in enclosed environments like cages and ponds. The inability to regulate food consumption can lead to wastage and consequent water pollution. This pollution, in turn, escalates the susceptibility of fish to disease outbreaks. Accumulation of leftover feed and fecal matter elevates ammonia levels in the water, posing a grave risk as ammonia toxicity detrimentally impacts aquatic organisms, causing stunted growth and compromised fish health (Yousefi et al 2020). This study notably observed that treatment A exhibited a relative efficiency in which minimal leftover feed was evident, unlike treatment C (6%) that resulted in measurable losses. Adequate and sustainable aquaculture hinges on the assurance of ample feed provision. To maximize profits, the optimization of feeding strategies becomes imperative (Mengistu et al 2020; Wijayanto et al 2022; Mohammady et al 2023).

FCR in aquaculture is strongly influenced by fish survival. FCR is determined by individual feed efficiency and SR. The impact of fish mortality during rearing does not contribute to the overall harvested biomass, despite their consumption of fish feed. The SR of all treatments in this research was 100%. While the ideal feeding rate varies across species, Mohammady et al (2023) showed that the optimal feeding rate for tilapia is 4%. Wijayanto et al (2022) reported the optimal feeding rate for barramundi fish of 3.95% of fish biomass per day for growth and 3.96% for profit. Furthermore, Hassan et al (2021) found the use of 6.5% biomass per day is optimal for the growth, fish survival, and preventing cannibalism in barramundi fish. Eroldogan et al (2004) explained that in the case of seabass (*Dicentrarchus labrax*), the optimal feeding rate varies depending on the media used, where at a salinity of 0.4 ppt the optimal feeding rate is 3%, fish biomass per day and 3.5% at 40 ppt salinity. This is likely to occur because salinity affects fish osmoregulation, creating variations in energy requirements and feed requirements.

As explained by Eroldogan et al (2004), fish feed stands as a pivotal determinant in the realm of commercial fish farming, given its pronounced influence on fish growth and feed wastage within the cultivation environment. The research conducted by Norazmi-Lokman et al (2020) underscored that administering feed three times a day yielded the most favorable FCR for juvenile Siamese fighting fish (*Betta splendens*) and guppies (*Poecilia reticulata*). Attaining an optimal feeding rate can consequently engender maximal feed consumption, minimal wastage, heightened nutritional efficiency, improved feed conversion efficiency, diminished production expenses, and a mitigated environmental footprint in terms of air pollution. The costs associated with feed can soar to surpass 50% of the total expenses in fish cultivation. It is imperative to avoid overfeeding, as it can lead to gastrointestinal overload in fish, thereby impairing nutrient digestion and absorption. This phenomenon further perturbs air quality parameters, amplifying production costs, as observed by Mohammady et al (2023).

Fish growth, SR, FCR, and profit stand as the central considerations for fish farmers. Profit motivates fish farmers to engage in grouper fish cultivation, while growth and SR affect the production, which subsequently interacts with selling prices to shape economic outcomes. FCR directly relates to costs, with feed costs constituting the predominant share of variable costs in intensive fish farming. Further impacting profits are administrative and other expenses. Typically, an FCR exceeding 2 is generally considered acceptable. This standard, however, may shift based on fluctuating feed prices. Aquaculture practitioners attach significant importance to FCR and feed costs due to the substantial proportion they occupy within total variable costs. This aspect is particularly pronounced in regions characterized by high feed prices, leading to escalated variable costs. Studies by El-Sayed (1999), Craig & Helfrich (2009), and Mengistu et al (2020) underscore the pivotal role of FCR and feed costs.

In the context where treatment A exhibits an FCR surpassing 3, treatment B demonstrates a BCR exceeding 1, signifying greater profitability. This outcome arises from the relatively elevated market value of TGGG grouper in relation to fish feed costs (Wijayanto et al 2022, 2023a, b). According to DJPB (2017), the BCR for TGGG hybrid grouper culture in floating net cages within a marine environment is approximately 1.4.

Throughout the research, the water quality was carefully maintained to support the well-being of the fish, including water temperature, pH, and DO. Water quality is important in fish farming, as inadequate water quality can induce stress, foster disease, and ultimately lead to fish mortality. Poor water quality can result from excessive accumulation of feed remnants and waste. To address this, water recirculation systems should be applied to maintain the water quality, optimize water usage, and promote environmentally sustainable aquaculture practices. In the context of coastal cultivation, mangroves can enhance the water quality for more optimal fish growth (Venkatachalam et al 2018).

The findings of this study underscore the critical role of feed management, considering that feed constitutes the largest cost variable in intensive fish farming (Gao et al 2022; Wijayanto et al 2022). Feed expenses can even account for more than 70% of variable costs (El-Sayed et al 2015; Dennis 2021). The mean BCR value recorded for treatment A in this investigation stands at 1.08, indicating that each unit of currency (IDR 1) spent yields an income of IDR 1.08. Effective feed management holds the potential to significantly curtail costs and enhance profitability. This management encompasses aspects such as selecting appropriate feed sizes, types, feeding rates, frequencies, and techniques. Optimal feeding practices not only foster fish growth, minimize feed conversion rates, and bolster fish survival rates but also contribute to cost reduction, water quality maintenance, and diminished water pollution (Villarroel et al 2011; da Cunha et al 2013; Gao et al 2022; Wijayanto et al 2022).

Conclusions. The results of this research indicate that optimal feeding can improve the TGGG hybrid grouper aquaculture business. Treatment A appeared as the best treatment as it exhibited the highest growth (WGR 38.0% and SGR 1.04% per day), the most efficient FCR (i.e 3.69) and the highest BCR (i.e 1.08). This research found that the optimal feeding is 4.10% fish biomass per day for BCR, 4.19% fish biomass per day for FCR, and 4.23% fish biomass per day for both WGR and SGR.

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Conflict of interest. The authors declare that there is no conflict of interest.

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