Enhancing the growth performance of catfish (*Clarias* sp.) by the application of feed derived from fermented food waste

[1]Yuli Andriani, [1]Muhamad D. Cahya, [1]Fittrie M. Pratiwy, [2]Putri W. Harlina, [3]Risdiana, [1]Iskandar

[1] Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia; [2] Department of Food Industrial Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, 45363 Bandung, Indonesia; [3] Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia. Corresponding author: Y. Andriani, yuli.andriani@unpad.ac.id

Abstract. Catfish (*Clarias* sp.) is one of the leading products in Indonesian aquaculture due to its ease of cultivation, great tolerance to poor water quality, relatively low price, rapid growth, and high nutritional content. Increasing catfish aquaculture production requires a consistent supply of high-quality feed. However, commercial feed of superior quality is often purchased at a relatively high price. The utilization of alternative feed ingredients, such as fermented food waste meal (FFWM), offers a viable solution for reducing feed costs. Therefore, this research aimed to investigate the influences of incorporating different levels (0%, 15%, 20%, 25%, and 30%) of FFWM into the test feed. The key parameters assessed included specific growth rate, feed conversion ratio, protease enzyme activity, and protein retention. The results show that the addition of 20% FFWM yielded the best performance in terms of specific growth rate (1.56), feed conversion ratio (2.46), protease enzyme activity (103 U/mg protein), and protein retention (24.71%). These results indicated the potential of utilizing FFWMs in catfish feed to enhance the growth performance of fingerlings.

Key Words: *Clarias* sp., fermented food waste meal, fish feed, growth.

Introduction. The fisheries industry plays a crucial role in addressing the growing global need for food. Based on the findings of Béné et al (2016), the fisheries industry demonstrated a production capacity in 2010 that was twice as high as that of poultry production. In this particular context, the Catfish species (*Clarias* sp.) has considerable potential as a valuable asset for the advancement of fishery practices, owing to its cultivation convenience, accelerated growth rate, and substantial nutritional value. In the context of Indonesia, the production of catfish holds significant importance, as evidenced by the substantial national production figure of 1,027,032.54 tons in the year 2018 (KKP 2021). Nevertheless, there is a need to boost the growth response of catfish in order to meet the increasing demand for fish.

Fish growth is a physiological phenomenon that occurs as a result of the assimilation and use of energy and necessary amino acids derived from the consumption of feed (Andriani et al 2016). In order to enhance the growth response of catfish, a range of strategies can be utilized, including genetic engineering (Ndimele & Owodeinde 2012; Olele & Tighiri 2013) and enhancements in the nutritional composition of diet (Putra et al 2020; Rosenau et al 2021). The aforementioned objective can be accomplished through the alteration of biomaterial feed constituents in order to augment digestibility, enhance quality, and stimulate fish growth. Fermentation is a process that can be utilized to modify feed materials, resulting in the breakdown of complicated chemicals and the synthesis of various types of vitamins. The fermentation and modification process presents potential avenues for the utilization of alternative feed sources, such as food waste (Pamungkas 2011; Andriani et al 2021).

The issue of food waste presents substantial economic, social, and environmental implications. According to the findings of Cheng et al (2014) a total of 1.3 billion tons of food waste was generated worldwide in the year 2012, resulting in a significant economic loss of USD 936 billion. Concurrently Wong et al (2016) observed that during the same year, around 925 million individuals were affected by hunger worldwide. In addition, inadequate management of food waste results in adverse environmental consequences, such as the generation of methane gas (CH_4). It is worth noting that methane gas exhibits a global warming potential that is 30 times more than that of carbon dioxide (CO_2) when it undergoes decomposition (Rajeh et al 2021).

In recent years, there has been an increasing level of interest among specialists and fish farmers regarding the utilization of food waste or fermented food waste as a viable substitute for fish feed (Cheng et al 2014; Chen et al 2015; Cheng & Lo 2016; Choi et al 2016; Sugiura et al 2009; Wong et al 2016). The conversion of food waste, which is commonly regarded as having little value, into feed that is abundant in nutrients through the process of fermentation presents a promising opportunity for the cost-effective and environmentally sustainable manufacture of fish feed.

The exploitation of fermented food waste as fish feed has numerous benefits, such as diminishing reliance on commercially produced feed, optimizing the utilization of food waste, and addressing the diverse challenges related with food waste. Hence, the main objective of this research project is to investigate the impact and quantity of fermented food waste meal (FFWM) on the growth response of juvenile catfish.

Material and Method

Experimental design. The research was conducted during March-June 2022 at the Ciparanje Aquaculture Area, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran. This research was conducted using completely randomized design (CRD) with 5 treatments and 3 replicates. The treatments were the addition of FRWM at 0% (treatment A), 15% (treatment B), 20% (treatment C), 25% (treatment D) and 30% (treatment E).

Preparation of experimental diet. The food waste was obtained from the Jatinangor region through a series of processes including sorting, chopping, and fermentation. The fermentation process was performed using commercial probiotic BIOM-S, with a dosage of 8 mL per 100 grams of food waste. This fermentation process lasted for a duration of seven days. Following that, the food waste that underwent fermentation was transformed into a powdered form, and a comprehensive analysis of its amino acid composition was conducted. The experimental diet was designed to have an isoprotein composition with crude protein content of 30% by incorporating different amounts of FFWM, specifically 0%, 15%, 20%, 25%, and 30%. These proportions were assigned as treatments A, B, C, D, and E respectively. The nutritional composition of the experimental diet was determined through the use of proximate analysis, as outlined in Table 1.

Table 1

The proximate analysis of experimental diets

Treatment	*Protein (%)*	*Lipid (%)*	*Crude fiber (%)*	*Carbohydrate (%)*	*E/P ratio (%)*
A	29.20	6.48	7.52	39.00	14.16
B	30.36	7.91	6.22	40.17	13.94
C	30.78	7.56	5.05	41.57	13.62
D	29.58	6.33	6.67	43.81	13.84
E	29.44	6.35	6.58	42.49	14.08

Feeding trial. The present study was carried out at the Ciparanje Aquaculture Area, which is affiliated with the Faculty of Fisheries and Marine Sciences at Universitas Padjadjaran. The experiment utilized catfish fingerlings with an average length of 6±0.283 cm, and the duration of the experiment was 40 days. The feed was provided in a tri-daily manner, with a dosage equivalent to 3% of the total biomass of the fish. The removal of uneaten feed and fish waste occurred on a bi-daily basis, with a subsequent replacement of 50% of the water volume. Throughout the duration of the experiment, the recorded parameters included water temperature, dissolved oxygen (DO) levels, pH, and ammonia concentrations which were observed at regular intervals of 10 days, and exhibited a variety of values.

The parameters, namely specific growth rate (SGR), feed conversion ratio (FCR), survival rate (SR), and protein retention (PR), were calculated utilizing the methods established by Effendie (1997), Tacon (1987), Gou et al (2012):

$$SGR\ (\%\ day^{-1}) = (\ln Wt - \ln W0) \times 100 / t$$

$$FCR = feed\ intake / (Wt + D) - W0$$

$$SR\ (\%) = (final\ fish\ count / initial\ fish\ count) \times 100$$

$$PR\ (\%) = (final\ body\ protein - initial\ body\ protein) \times 100 / protein\ fed$$

From the equations, t represents the total number of testing days, ln W0 denotes the natural logarithm of the initial weight of catfish fingerlings, ln Wt signifies the natural logarithm of the final weight of catfish fingerlings, W0 is initial weight of fish, Wt is the final weight of fish, and D is the weight of fish that died during the testing process.

Digestive enzyme activity. The assessment of protease enzyme activity was conducted utilizing the Kunitz test method. The fish intestinal samples were subjected to grinding and subsequent dissolution in 1 mL of distilled water. The resulting mixture was then subjected to centrifugation at a speed of 6000 x g for a duration of 10 minutes at a temperature of 4°C. The 100 µL of supernatant was combined with 500 µL of a 0.1% casein solution and subjected to incubation at a temperature of 40°C for a duration of 30 minutes. Following that, a solution consisting of 500 µL of trichloroacetic acid (TCA) with a concentration of 12% was introduced, accompanied by the addition of distilled water to achieve a total volume of 2 mL. The measurement of absorbance was conducted using a spectrophotometer at a specific wavelength of 280 nm. The calculation of protease enzyme activity was performed using the following equation:

$$Enzyme\ activity = \frac{Sample\ absorbance}{0.001 \times hydrolysis\ time\ (minutes) \times enzyme\ volume\ (mL)}$$

Statistical analysis. One-way analysis of variance (ANOVA) was used to determine the level of differences in SGR, FCR, SR, and PR. In cases where significant differences were detected based on the ANOVA test results, Duncan's multiple range test ($p < 0.05$) was conducted to identify specific variations.

Results

Growth rate. The introduction of FFWM had an impact on the growth of catfish in all treatment groups. According to the data presented in Table 2, the inclusion of 20% FFWM in the feed (referred to as Treatment C) resulted in the highest specific growth rate of 1.56%.

Table 2

The specific growth rate of catfish fingerlings

Treatment	*Specific growth rate (% day^{-1})*
A	1.08±0.05^{a}
B	1.39±0.11^{bc}
C	1.56±0.25^{c}
D	1.18±0.10^{ab}
E	1.18±0.09^{ab}

*The means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ according to Duncan's multiple range test.

Additionally, as indicated in Table 1, this treatment exhibited the most favorable nutritional composition, which was deemed satisfactory for promoting appropriate growth. The increased protein content in the meal permitted enhanced protein absorption by the fish's body, thus leading to an improvement in their growth rate.

Survival rate (SR). The inclusion of FFWM in the fish feed demonstrated no substantial impact on the SR of fish, as evidenced by the results presented in Table 3, therefore implying the absence of any adverse effects. Overall, the utilization of feed supplemented with FFWM resulted in a SR over 85%, so satisfying the minimum SR criteria specified in the Indonesian National Standard (SNI 6484.4.2014) for the production of Dumbo catfish (*Clarias* sp.) fingerlings. Based on the established criterion, it is expected that the minimum SR for phase IV rearing (5-7 cm length) should be at least 80%.

Table 3

The survival rate of catfish fingerlings

Treatment	*Survival rate (%)*
A	85.00±0.50[a]
B	86.67±0.58[a]
C	86.67±0.29[a]
D	88.33±0.29[a]
E	85.00±0.50[a]

*The means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ according to Duncan's multiple range test.

Feed conversion ratio. The FCR serves as a metric for evaluating the quality of feed, whereby a lower number signifies a higher level of efficiency in feed usage. Table 4 demonstrates that Treatment C displayed the most favorable FCR, as seen by its value of 2.49. The observed phenomenon can be ascribed to the nutritional composition of the feed, which satisfied the dietary needs of the fish and upheld a harmonious balance of nutrients in comparison to alternative treatments.

Table 4

The feed convertion ratio of catfish fingerlings

Treatment	*Feed conversion ratio*
A	3.66±0.14[b]
B	2.76±0.35[ab]
C	2.49±0.46[a]
D	3.22±0.61[ab]
E	3.25±0.67[ab]

*The means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ according to Duncan's multiple range test.

Protease enzyme activity. The assessment of fish's capacity to metabolize the offered feed is determined by the level of digestive enzyme activity (Gawlicka et al 2000; Melianawati & Pratiwi 2011). According to the data presented in Figure 1, the administration of FFWM as feed resulted in an increase in the activity of protease enzymes inside the digestive tract of fish.

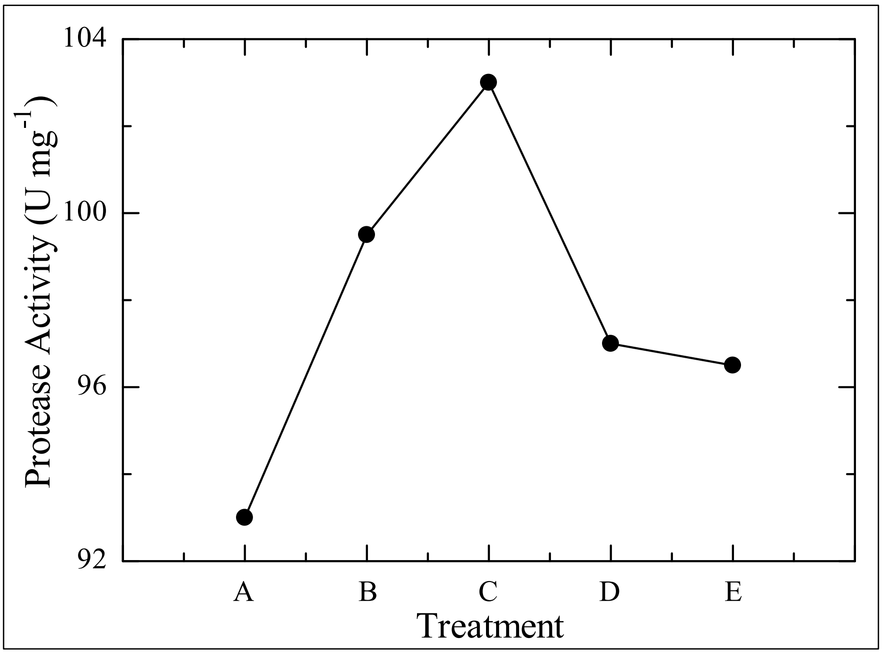

Figure 1. Protease enzyme activity in the digestive system of the experimental fish.

Protein retention. The quantification of PR in fish was conducted to ascertain the extent to which protein was absorbed from the given meal. Based on the findings presented in Table 5, it can be observed that Treatment C exhibited the highest PR value of 24.71%. This outcome may be attributed to the fact that Treatment C possessed the highest protein content of 30.78% among all the treatments. The protein composition of the diet has an impact on the absorption of body proteins and the usage of energy, thereby facilitating tissue growth and ultimately enhancing the overall rate of growth.

Table 5

The protein retention of catfish fingerlings

Treatment	*Protein retention (%)*
A	7.20 ± 0.17^{a}
B	20.40 ± 0.14^{c}
C	24.71 ± 0.15^{d}
D	17.65 ± 0.07^{b}
E	17.46 ± 0.06^{b}

*The means followed by the same letter(s) in the same column are not significantly different at $p < 0.05$ according to Duncan's multiple range test.

Water quality. Specifically, the water temperature ranged from 29.5 to 31°C, DO levels varied between 4.1 and 7.0 mg L^{-1}, pH values fluctuated between 6.0 and 7.4, and ammonia concentrations spanned from 0.003 to 0.03 mg L^{-1}. The water quality metrics exhibited values within the ideal range, hence facilitating the growth rate of fingerlings.

Discussion. The inclusion of FFWM in the formulation of fish feed resulted in beneficial effects on various parameters including the SGR, SR, FCR, protease enzyme activity, and PR in catfish fingerlings. Protein serves as the primary provider of essential amino acids that are necessary for fish to develop and enhance bodily tissues, including musculature, skeletal structures, and internal organs. Moreover, it assumes a crucial function in the processes of metabolism, hormonal activities, and the regulation of enzymes (Li et al 2009; Yusuf et al 2016). The composition and variety of amino acids found in feed protein have a direct impact on the process of fish body protein synthesis and the overall availability of nutrients.

The specific growth rate of fish is typically impacted by factors such as the rate of ingestion, the digestibility of the meal, and the nutritional content of the feed (Effendie 1997; Rostika et al 2023). The augmentation of protein content in feed has been observed to have a positive impact on the growth of fish, provided that their protein requirements are adequately fulfilled (Figure 2). In the context of aquaculture, the composition of feed plays a critical role in meeting the protein needs of farmed fish. Achieving optimal protein consumption for growth necessitates the establishment of a balanced protein-to-energy ratio in feed (Ali & Jauncey 2005). Furthermore, it is imperative to consider the aspect of digestibility, as feed with low digestibility has the potential to diminish the effectiveness of protein utilization.

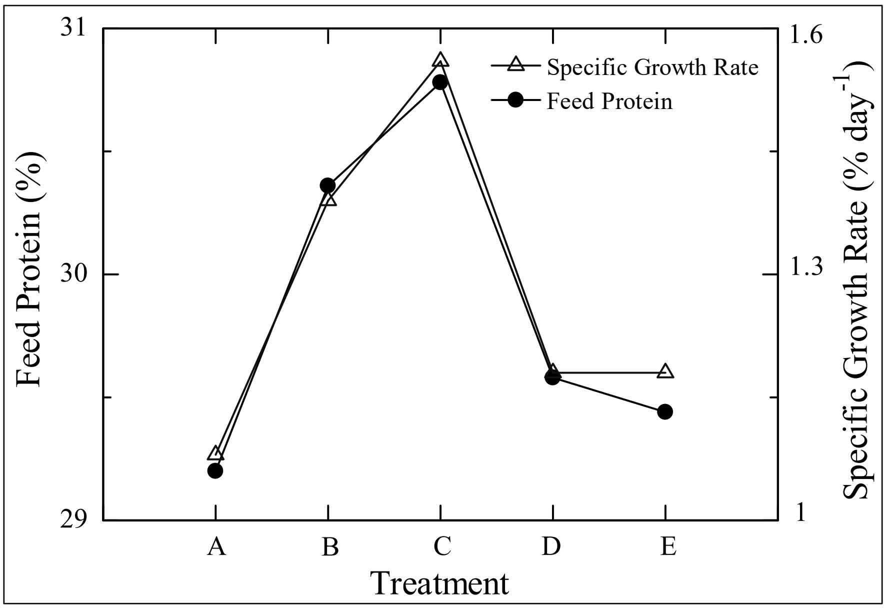

Figure 2. Relations between feed protein and specific growth rate of experimental fish.

The importance of protein in fish feed as a crucial component for development, health, and cellular repair has been highlighted by Sanz et al (2000). In addition to the quantity of protein, the presence of high-quality amino acids is also necessary for the growth and development of fish. Lysine, an essential amino acid, has a significant role in the development of muscles, growth of bones, and availability of energy in fish (Hamid et al 2016; Yusuf et al 2016). The enhancement of feed nutritional value and promotion of fish growth can be achieved through the improvement of amino acids, namely lysine (Li et al 2009; Yusuf et al 2016). The augmentation of lysine in FFWM enhances the protein content of *Clarias* sp. fingerlings as a result of its physiological role (Li et al 2009; Djissou et al 2016; Yusuf et al 2016). According to the data presented in Figure 3, it can be noticed that the fermentation process of food waste resulted in a 16% rise in lysine content. This increase in lysine content was found to be associated with a greater growth rate in catfish feed that included fermented food waste. These findings suggest that the elevated lysine content contributed to the enhanced growth rate observed in catfish.

Based on the data presented in Figure 3, the enhanced amino acid quality observed in the food waste flour can be attributed to the fermentation process. This process facilitates the breakdown of the protein component into more basic forms, such as amino acids, resulting in an overall increase in the amino acid content of the food waste flour. Out of all the treatments examined, the Treatment C had the most favorable nutritional and amino acid composition, resulting in enhanced growth performance. The enhanced quality of amino acids has a positive effect on the pace of growth. The amino acid lysine, which is classified as essential, plays a critical part in the processes of bone growth, muscle development, and energy production (Yusuf et al 2016). Consequently, the incorporation of FFWM as a feed supplement resulted in an increased growth response in the experimental fish, mostly attributed to its superior amino acid composition.

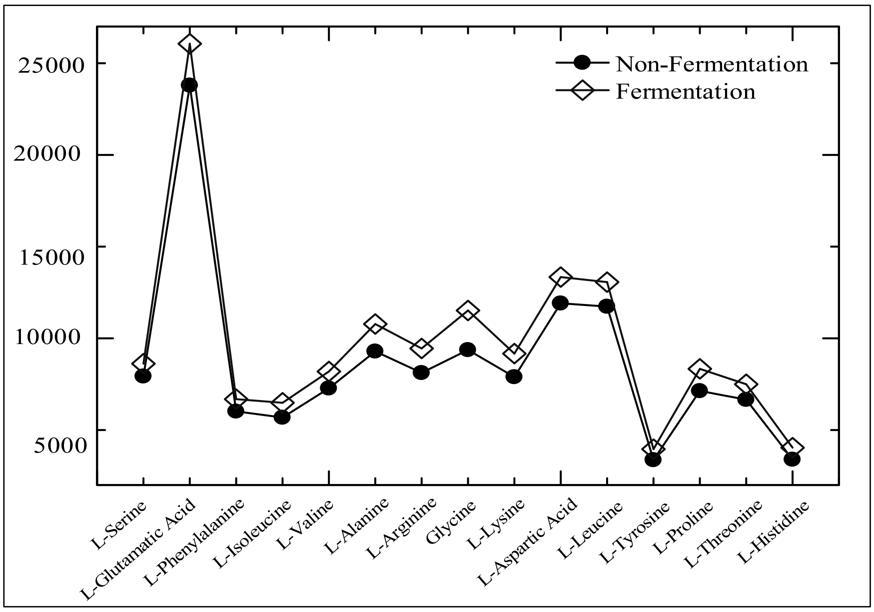

Figure 3. Changes in the amino acid quality of FFWM.

The growth performance in Treatment C was also affected by the lipid content. Lipid plays a crucial role in providing energy for the physiological activities of fish, which is commonly referred to as the protein-sparing effect (Satpathy et al 2003; Marzuqi et al 2019). The utilization of protein as the principal energy source for metabolic and everyday activities in fish is triggered by inadequate quantities of lipid and carbohydrates in their feed (Marzuqi et al 2019). This utilization of protein as an energy source results in reduced protein availability, thus impacting the pace of growth.

Previous studies have demonstrated that the fermentation process applied to food waste successfully facilitates the decomposition of proteins into amino acids and peptides. Additionally, this procedure has been observed to decrease particle size, resulting in heightened protease activity within the digestive tract of the experimental fish. The increased concentration of peptides and amino acids, along with reduced particle sizes, had a notable impact on the rate of nutrient absorption from the diet. Zhang et al (2017) posited that the absorption of peptides via the intestinal wall leads to the augmentation of intestinal villus growth, facilitation of intestinal development, and elevation of digestive enzyme activity in fish. The findings of this study suggest that the activity of protease enzymes was observed to increase with the introduction of FFWM, but subsequently decreased with the incorporation of Treatment C. The findings of this study align with the findings reported by Ao et al (2021) about the supplementation of fermented kitchen waste flour at a concentration of 12%. This supplementation resulted in an increase in protease activity inside the digestive tract of crucian carp (*Carassius auratus gibelio*), surpassing the activity observed when employing a concentration of 30%.

According to Dawood et al (2020) an augmentation in the enzymatic activity of the digestive system in fish may have a beneficial impact on feed efficiency. This finding is consistent with previous study on growth and FCR, since the inclusion of FFWM resulted in increased growth rates and decreased FCR values compared to the control group. The addition of FFWM in the diet resulted in enhanced feed efficiency, as evidenced by the reduced FCR. This suggests that the fermentation process stimulated enzyme activity, leading to notable improvements in feed quality, digestibility, growth, and overall feed efficiency (Yang et al 2016; Dawood & Koshio 2020).

The provision of feed that is of superior quality and can be easily digested plays a crucial role in ensuring that fish have access to adequate energy levels, which are necessary to meet their metabolic and development requirements. In addition, the utilization of easily digestible feed serves to reduce waste and mitigate the potential release of organic compounds, such as nitrogen, phosphorus, and carbon, which may originate from undigested feed. The process of fermenting food waste has been found to have a beneficial effect on the simplification of intricate chemical linkages, resulting in increased digestibility of feed and improved efficiency of energy absorption (Andriani et al 2016; Suprayudi et al 2012).

The protein retention value is influenced by the energy-to-protein ratio, as noted by Andriani et al (2018). According to the data presented in Table 1, Treatment C exhibited an energy-to-protein ratio of 13.62 kcal g^{-1}, which closely approximated the standard ratio. According to Lovell (1989) the recommended energy-to-protein ratio for promoting growth in channel catfish weighing 3 grams is 10.2 kcal g^{-1}. According to Robinson & Li (2002), it was shown that the energy-to-protein ratio for feed containing protein levels of 28% and 32% is 11.8 kcal g^{-1} and 10.3 kcal g^{-1}, respectively. The negative consequences of imbalances in the protein-to-energy ratio in feed are evident as fish are subjected to an excessive intake of energy, leading to the accumulation of adipose tissue and subsequently diminishing protein retention within their body tissues (Yanto et al 2018). Hence, it can be deduced that an increased energy-to-protein ratio in feed results in a diminished efficiency of protein absorption.

In addition to its protein content, the inclusion of crude fiber in feed has a significant impact on the growth performance of fish. Crude fiber is classified as a non-digestible nutrient, and as a result, the consumption of feed with a high crude fiber content has a detrimental effect on the growth of animals. The control treatment exhibited the highest crude fiber content (7.52%), resulting in a significantly lower growth rate in comparison to Treatment C. The presence of a significant amount of crude fiber in fish feed poses a challenge to the process of digestion, mostly because the digestive system lacks the necessary cellulase enzymes. Consequently, this can have a detrimental impact on the absorption of other essential nutrients (Hepher 1988; Andriani et al 2016).

According to the data presented in Figure 4, it can be observed that Treatment C exhibited a reduced feed conversion ratio and improved feed digestibility due to its comparatively lower crude fiber content, in comparison to the other treatments. Furthermore, the fermentation process carried out on feed materials resulted in the reduction of particle size and the conversion of complicated substances into simpler forms that are more readily digested (Suprayudi et al 2012). The reduced particle size after fermentation resulted in heightened reactivity of feed constituents with digestive enzymes, owing to the provision of an expanded surface area, hence facilitating enhanced ion transfer. The data suggest that the application of FFWM has the potential to enhance the quality of feed ingredients, leading to a reduction in the FCR value.

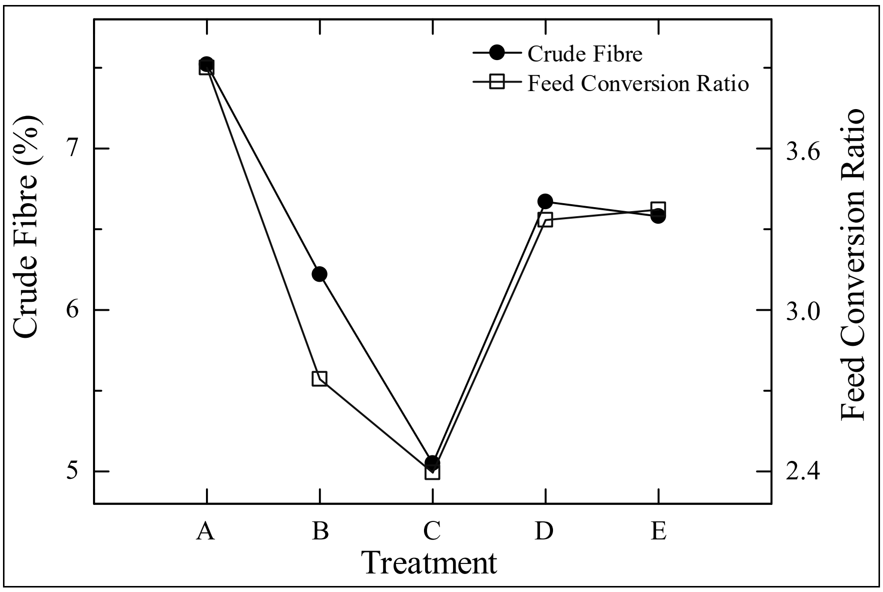

Figure 4. Relations between the crude fiber and feed conversion ratio of experimental fish.

Conclusions. The findings of this study indicate that the inclusion of FFWM at a 20% rate (Treatment C) resulted in the most favorable outcomes in terms of growth rate, feed conversion ratio, protein retention, and digestive enzyme activity. Specifically, the growth rate was observed to be 1.56%, the feed conversion ratio was 2.49, the protein retention was 24.71%, and the digestive enzyme activity was 103 U mg^{-1} protein. The survival rate of Treatment D (25% FFWM) was found to be the highest at 88.33%, and this value did not exhibit a statistically significant difference when compared to Treatment C. The enhanced growth performance observed in Treatment C can be attributed to the well-balanced nutritional composition of the feed, which was supplemented with 20% FFWM. Hence, the incorporation of FFWMs in pisciculture exhibits the prospect for additional advancement as a self-sufficient dietary alternative to sustain aquaculture operations.

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

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Authors:
Yuli Andriani, Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia, e-mail: yuli.andriani@unpad.ac.id
Muhamad Dwi Cahya, Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia, e-mail: keealf@hotmail.com
Fittrie Meyllianawaty Pratiwy, Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia, e-mail: fittrie.pratiwy@unpad.ac.id
Putri Widyanti Harlina, Department of Food Industrial Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, 45363 Bandung, Indonesia, e-mail: zdcc@ukm.edu.my
Risdiana, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia, e-mail: @unpad.ac.id
Iskandar, Department of Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran, West Java, 45363, Indonesia, e-mail: fittrie.pratiwy@unpad.ac.id

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