Growth performance and economic analysis of incorporating algal meal in feed formulation of flathead grey mullet fry

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Abstract. The effects of algal meal (AM) from *Chaetomorpha* sp. as a replacement for fish meal (FM) on flathead grey mullet (FGM, *Mugil cephalus*) fry growth, feed utilization, survival performance, economic analysis, and cost-benefit analysis were investigated. A plastic container containing 70 liters of water was stocked with thirty FGM fry of the same size and weight. A total of three formulated diets were prepared: Feed 1 with 0% AM and 20% FM, Feed 2 with 10% AM and 10% FM, and Feed 3 with 20% AM and 0% FM. A 45-day experiment was performed, featuring three repetitions for each group. Feed formulations containing different levels of AM and FM revealed that no significant effect on the survival and the growth of FGM fry ($p > 0.05$). Despite this, Feeds 1 (32.22±4.01%) and 2 (32.22±4.44%) had significantly higher survival rates ($p \leq 0.05$) than Feed 3 (16.67±3.85%). The lower survival rate of FGM fry observed may be attributed to elevated ammonia and nitrite levels in the recorded water parameters. The feed intake of Feed 1 (0.10±0.01) and Feed 2 (0.10±0.01) were significantly increased ($p \leq 0.05$) than Feed 3 (0.05±0.01). Additionally, the proximate composition of feed (moisture, ash, crude fiber, crude fat, and crude protein) significantly improved ($p \leq 0.05$) with the addition of varying levels of AM and FM. Moreover, the economic conversion rate (ECR) for Feed 2 (0.44±0.12) and Feed 3 (0.43±0.14) was lower than that of Feed 1 (0.47±0.14), indicating that these feeds were more cost-effective. As a result, farmers can enhance survival rates, feed efficiency, and growth in FGM fry culture by substituting 10% algal meal for the more expensive fish meal.

Key Words: algal meal, *Chaetomorpha* sp., economic analysis, feed utilization, fish meal, *Mugil cephalus*.

Introduction. The aquaculture industry provides cheap and valuable animal protein to the world's rapidly growing population (Elhetawy et al 2021). As a contributing species to large fisheries in estuarine and coastal regions, flathead grey mullet (FGM, *Mugil cephalus*) accounts for 2.6% of the total production of marine fish by 2020 (Mondal et al 2015; FAO 2022). In Mediterranean, Southern, and Southeast Asian regions, the species is a significant finfish species because it grows rapidly, is well adapted to captivity, eats omnivorously, and has a high market value of dried eggs (Whitfield et al 2012; Gisbert et al 2016). Mullets are primarily produced in polycultures, along with milkfish, tilapia, and carp (Biswas et al 2012). However, due to the increased demand for this species, intensive monoculture has been developed (Gisbert et al 2016). In intensive fish farming operations, feed and feeding costs account for approximately 40-70% of operating expenses, depending on the intensity of farming (Sharawy et al 2020). This significant expense is further exacerbated by the progressive depletion of global fish stocks (Perez-Velazquez et al 2018), as limited availability and high demand have driven up prices of fish meal and fish oil, creating a constraint on the continued development of aquaculture (Tacon et al 2011; Perez-Velazquez et al 2019).

FAO emphasizes the importance of finding alternatives to meet fish oil and fish meal demand (Gephart et al 2021; Shafique et al 2021). Therefore, in response to the increase in prices, which ranges from 1,700 USD to 1,800 USD per metric ton (World Bank 2024), and the decreasing availability of fish meal as a protein source, manufacturers and scientists are exploring alternatives (Welker et al 2014). Over the past decade, aquaculture has made strides in reducing the reliance on fish meal and fish oil in aquafeeds, however, as the production of farmed species continues to grow, there remains an ongoing need for these ingredients (Radhakrishnan et al 2015).

One such alternative is algal meal, which is significantly cheaper at 800 USD to 1,000 USD per metric ton (Wiatrowski et al 2022; Klein & Davis 2023), making it a cost-effective and promising substitute for fish meal in aquafeeds. Algae have been researched recently as a potential protein source for it is more economical and sustainable than other sources of protein (Gokulakrishnan et al 2015). Macroalgae contain abundant non-starch polysaccharides, proteins, bioactive substances, lipids, vitamins, and minerals (Simtoe et al 2023). A macroalgae's protein content varies from 10 to 47% of its dry weight, with red algae constituting the majority of it (Simtoe et al 2023). There was a study that found 9 to 26% protein in green algae in dry weight, while 20.4 g/100 g was found for *Chaetomorpha* sp. (Tsutsui et al 2015; Fleurence et al 2018). There has also been evidence that this species of plant exhibits antioxidant properties, which means it may be a promising candidate for the purpose of stimulating growth (Gazali et al 2019). The fact that *Chaetomorpha* sp. may be able to substitute for fish meal makes it an interesting candidate for fish meal replacement trials.

Macroalgae have been extensively explored in aquaculture, and they're being used as potential immunostimulants. Researchers have found that algal species contain nutrients that support immune health and improve survival rates in aquatic organisms (Sattanathan et al 2020). An investigation was conducted on the effectiveness of *Chaetomorpha* sp. as an additive in the feed for *Penaeus monodon* in order to enhance its feed efficiency and performance (Genovese et al 2013). It is unknown whether *Chaetomorpha* sp. can be used as an additive in the feed as fish meal replacement of finfish such as FGM. Hence, in this study, we investigated the influence of varying levels of algae *Chaetomorpha* sp. inclusion as a fish meal alternative on the economic viability, survival rate, feed utilization, and growth performance of FGM fry.

Material and Method

Study site. Research was conducted at the Mindanao State University-Tawi-Tawi College of Technology and Oceanography, College of Fisheries, Multi-species hatchery, Sanga-Sanga, Bongao, Tawi-Tawi, Philippines (5º02′ 13.8″ N, 119º44′ 35.0″ E) for 45 days culture period, from September 5 to October 20, 2022.

Materials used and flow of the study. The materials used for fry collection included a plastic strainer, basin, large plastic box, aeration equipment, digital weighing scale, and ruler. For feed preparation, an oven, grinder mixer, aluminum tray, sack, glass container, plastic bags, refrigerator, algae (*Chaetomorpha* sp.), Philippine anchovy (*Encrasicholina oligobranchus*), corn meal, wheat flour, cornstarch, coconut oil, and water were utilized. During stocking, circular plastic tubs with a 70 L capacity, an aerator, an air stone, and an air hose were employed. Water maintenance was conducted using a thermometer, refractometer, API Freshwater Master Test Kit (which tests for ammonia, nitrite, and nitrate), and a hose for siphoning. The experimental set-up involved circular plastic containers with a 70 L water capacity, water pipes, aeration hoses, and air pipes. For feeding, a small plastic plate, aluminum tray, digital weighing scale, and aluminum foil were utilized. Lastly, during the sampling period, a weighing scale, ruler, plastic container, and basin were used. Moreover, the flow of the study is shown in Figure 1.

Fry collection and conditioning. FGM fry was obtained from the coastal area of MSU College of Fisheries with an initial mean weight and length of 0.076±0.003 g and 2.761± 0.034 cm, respectively. Fry was collected using plastic strainers early morning, placed in a basin, and brought to the hatchery. More than 300 collected FGM fry were acclimatized for three (3) days in two large plastic boxes filled with filtered seawater for initial conditioning. As part of the acclimation process, fish were fed ad-libitum with commercial feed, and continuous aeration was provided with a flow-through water system.

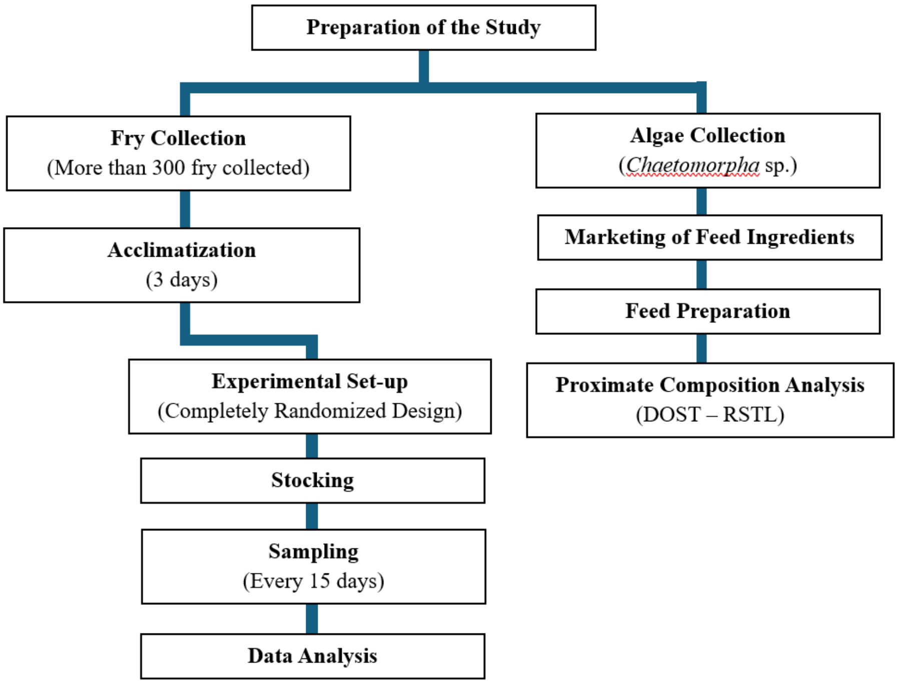

Figure 1. Flow of the experimental study.

Feed preparation. Approximately two kilograms of algae *Chaetomorpha* sp. was collected from the intertidal zone of Sanga-Sanga, Tawi-Tawi, Philippines, and then thoroughly washed in fresh water to remove salts. The algae were dried at 40°C in an oven overnight to prolong the shelf life and easy application of dried powder product, resulting in 8 to 10% moisture content. A grinder mixer was used to grind the dried algae and store it in a glass container until it was incorporated into the diet. Additionally, fish meal was prepared from fresh fish (*E. oligobranchus*) obtained from the local wet market, washed with freshwater, then dried in the oven overnight at 40°C. Dried fish was ground and stored in a glass container until used. The commercial ingredients such as corn meal, wheat flour, cornstarch, and coconut oil were procured from the local market. All the ingredients were combined in the necessary quantities for the trial diets (Table 1). To make the dough, water was added, then a considerable amount of oil was added before it was cooked. After preparing the formulated feed diets, they were flattened on an aluminum tray, and the sample was dried at 60°C for 12 hours in an oven to eliminate any remaining moisture. The dried formulated diets were ground using a coffee grinder, stored in plastic bags, labeled accordingly, and refrigerated at 4°C until needed. There were three diets prepared with 0%, 10%, and 20% powdered algae kg^{-1}.

Proximate composition analysis. A proximate analysis of all feed diets was performed by sending the feed sample to the Department of Science and Technology (DOST), Regional Standards and Testing Laboratory (RSTL), Zamboanga City, Philippines, for proximate components such as crude protein, crude fiber, moisture, crude fat, and ash. The moisture, ash and crude fiber were quantified using the gravimetric method, crude protein was determined by the Kjeldahl (block digestion) and steam distillation method, and crude fat was assessed through Soxtec extraction method.

Stocking. FGM fry (n = 270) was distributed into nine circular plastic tubs (70 L capacity), with each tub containing 30 active and uniform-sized fry maintained triplicate. Stocking was done early in the morning.

Table 1

List of ingredients and composition of the formulated experimental diets using *Chaetomorpha* sp. in place of fishmeal (g kg^{-1}) (Hairol et al 2022)

Ingredients	*Level of inclusion*		
	Feed 1	*Feed 2*	*Feed 3*
Algal meal (AM) (g)	0	100	200
Fish meal (FM) (g)	200	100	0
Starch (g)	200	200	200
Oil (mL)	50	50	50
Corn meal (g)	350	350	350
Wheat flour (g)	200	200	200
Total (g)	1,000	1,000	1,000

Water maintenance. A refractometer and thermometer were used to measure the salinity and temperature of the water, respectively. Both parameters were checked every day prior to feeding and after water was changed. Every 15 days, 100% of the water was changed. A siphon was used every morning to remove uneaten feed from the container. The ammonia, nitrite, and nitrate testing procedures involve precise steps to ensure accurate results. For ammonia testing, a clean test tube was filled with 5 mL of water, and 8 drops of Ammonia Test Solution #1 were added while holding the dropper bottle upside down to ensure uniformity. Following this, 8 drops from Ammonia Test Solution #2 were added, and the test tube was capped and shaken vigorously for 5 seconds before sitting for 5 minutes. The resulting color was then compared against a white area of the Ammonia Color Chart to determine the ppm (mg L^{-1}) of ammonia in the sample. In the nitrite test, another clean test tube was prepared with 5 mL of water, to which 5 drops of Nitrite Test Solution were added, again ensuring uniformity by holding the dropper bottle vertically. After capping and shaking the tube for 5 seconds, the results were compared to the Nitrite Color Chart after allowing 5 minutes for color development in a well-lit area. The closest match indicated the ppm of nitrite in the sample, and the test tube was rinsed afterward. Lastly, for the nitrate test, a clean test tube was filled with 5 mL of water and 10 drops of Nitrate Test Solution #1 were added while maintaining a vertical position for uniformity. The tube was then capped and inverted several times to mix, and 10 drops of Nitrate Test Solution #2 were added after shaking it vigorously for at least 30 seconds. After capping and shaking for 1 minute, the color developed over 5 minutes and was compared to the Nitrate Color Chart in a well-lit area against a white background, indicating the ppm of nitrate in the water sample. The test tube was rinsed after use. Each test required careful attention to detail to ensure the accuracy of the results.

Experimental design. This study employed a completely randomized design (CRD). There were nine circular plastic containers (70 L water capacity) containing a water pipe that continuously supplied sand-filtered seawater above the tubs (Figure 2), thus facilitating a flow-through system. Aeration hoses were connected to the air pipes above the plastic containers to supply continuous aeration.

Feeding. Fry FGM were fed twice daily, given in the morning and afternoon, with 10% average body weight (Maundu 2020). The experiment used three different dietary treatments: Feed 1 (0% AM and 20% FM), Feed 2 (10% AM and 10% FM), and Feed 3 (20% AM and 0% FM) (Mutia 2024).

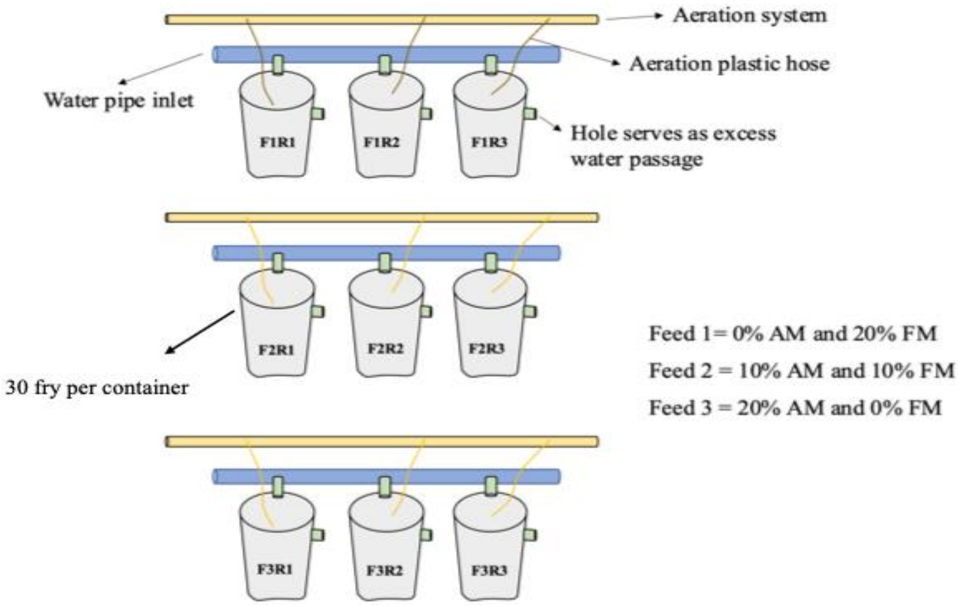

Figure 2. Experimental set-up of the study.

***Sampling**.* The growth, survival, and feed utilization of the FGM fry were monitored every 15 days from the day of stocking. The weight of 25% of FGM fry was measured in each tank. Following that, the samples were placed back in their respective tabs. In addition, the number of fry that survived in each tank was counted. The specific growth rate (SGR), survival rate (SR), feed intake (FI), and feed conversion ratio (FCR) were calculated using the formulas from Hairol et al (2022), while economic conversion rate (ECR) was determined based on the formula from Hien et al (2016):

A. Growth rate:

$$SGR = \frac{\ln(Wf) - \ln(Wi)}{\text{Days of culture}} \times 100$$

where: Wf = final weight
Wi = initial weight

B. Survival rate:

$$\text{Survival rate} = \frac{\text{Final number of stocks}}{\text{Initial number of stocks}} \times 100$$

C. Feed utilization:

$$FI = \text{Average body weight} \times \text{Feed rate} \times \text{Fish population}$$

$$FCR = \frac{\text{Total dry weight of feed (g)}}{\text{Body weight gain (g)}}$$

D. Economic analysis:

$$ECR = \text{Cost of diets } (kg^{-1}) \times FCR$$

***Data analysis**.* To identify significant differences in survival rate, feed utilization, and growth ($p \leq 0.05$), all data were statistically analyzed using IBM SPSS version 20 software using one-way analysis of variance (ANOVA). The result values were presented as mean±SEM (standard error of the mean). The mean was ranked using Duncan's Test, while homogeneity of variance was tested with Levene's Test.

Results

***Water parameters*.** Table 1 shows the water parameters of cultivated FGM fry at different feed diets. The temperature ranged from 29.52±0.05 to 30.02±0.03°C, while the salinity level recorded varied from 33.85±0.08 to 34.11±0.07‰, and the pH ranged from 7.94±0.02 to 8.14±0.01. Additionally, the ammonia level of the water ranged from 0.03±0.04 to 0.06±0.12 mg L^{-1}, while nitrite varied from 0.04±0.11 to 0.05±0.14 mg L^{-1} and nitrate level ranged from 10±0.15 to 13±0.05 mg L^{-1}.

Table 2

Water parameters of culture FGM fry

Water parameters	*Experiments*		
	Feed 1	*Feed 2*	*Feed 3*
Temperature (°C)	29.52±0.05[a]	30.02±0.03[a]	29.62±0.12[a]
Salinity (‰)	34.08±0.11[a]	34.11±0.07[a]	33.85±0.08[a]
pH	7.94±0.02[a]	7.98±0.03[a]	8.14±0.01[a]
Ammonia (mg L^{-1})	0.03±0.04[b]	0.03±0.05[b]	0.06±0.12[a]
Nitrite (mg L^{-1})	0.04±0.11[a]	0.04±0.22[a]	0.05±0.14[a]
Nitrate (mg L^{-1})	13±0.05[c]	11±0.09[b]	10±0.15 [a]

***Proximate composition of feed diets*.** The proximate composition of feed diets is shown in Table 2. Levels of moisture content varied from 11.83 to 14.37%, where Feed 1 was significantly lower among feed diets ($p \leq 0.05$). Crude protein and crude fat levels ranged from 10.27 to 20.79% and from 5.30 to 6.25%, respectively, indicating that Feed 1 was significantly higher than Feed 2 and 3 ($p \leq 0.05$). Levels of ash and crude fiber varied from 2.93 to 6.04% and from 0.73 to 4.71%, respectively, where Feed 3 was significantly higher among all feed diets ($p \leq 0.05$).

Table 3

Proximate composition (%) of experimental diets tested with varying inclusion levels of *Chaetomorpha* sp. to substitute fish meal

[1]*Feed diets*	*Moisture*	*Crude protein*	*Crude fat*	*Ash*	*Crude fiber*
Feed 1	11.83±0.003[c]	20.79±0.003[a]	6.25±0.003[a]	2.93±0.007[c]	0.73±0.007[c]
Feed 2	14.37±0.003[a]	15.65±0.003[b]	6.03±0.003[b]	4.44±0.003[b]	2.96±0.003[b]
Feed 3	13.63±0.033[b]	10.27±0.003[c]	5.30±0.003[c]	6.04±0.003[a]	4.71±0.007[a]

[1] Values are means ± SEM (standard error mean). Means that different letters within the row are significantly different. Feed 1, 0% AM and 20% FM: Feed 2, 10% AM and 10% FM: Feed 3, 20% AM and 0% FM.

***Growth, survival, and feed utilization of FGM fry*.** Figure 3 shows the SGR of FGM fry. SGR of Feed 1, 2, and 3 were 0.69±0.15% day^{-1}, 0.64±0.13% day^{-1}, and 0.55±0.10% day^{-1}, respectively, indicating that there was no significant difference among feed diets ($p \geq 0.05$). In addition, the survival rate of Feed 1 (32.22±4.01%) and Feed 2 (32.22±4.44%) was significantly different ($p \leq 0.05$) than Feed 3 (16.67±3.85%) (Figure 4). Moreover, Figure 5 shows the FI and FCR values of FGM fry. In terms of FI, the FI of Feed 1 (0.10±0.01) and Feed 2 (0.10±0.01) were significantly higher ($p \leq 0.05$) than Feed 3 (0.05±0.01). Additionally, the incorporation of *Chaetomorpha* sp. and fishmeal had no significant effect in terms of FCR.

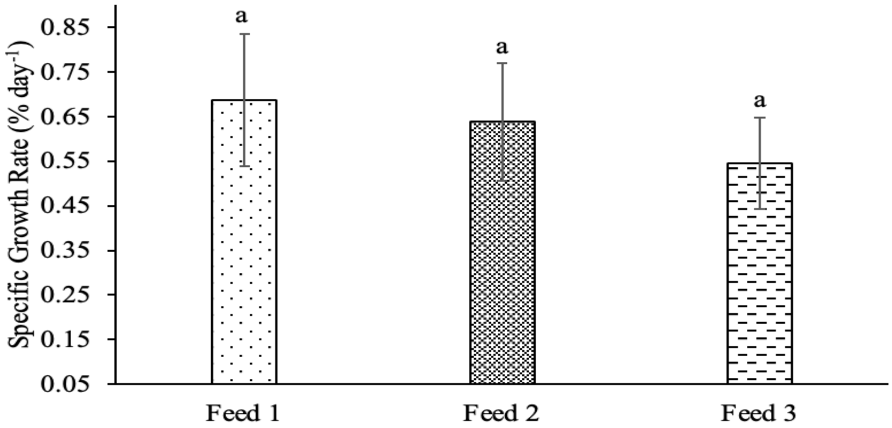

Figure 3. Specific growth rate of FGM fry in terms of weight fed with formulated feeds with different inclusion levels of *Chaetomorpha* sp. as replacement to fishmeal.

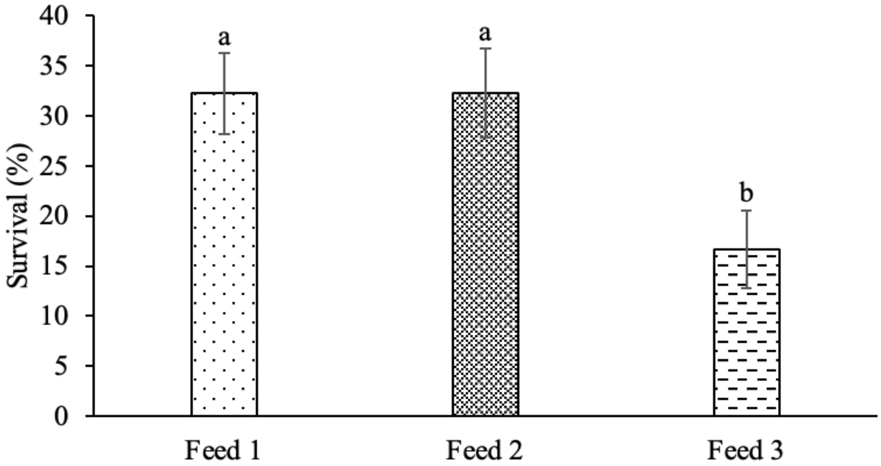

Figure 4. Survival rate of FGM fry fed with formulated feeds with different inclusion level of *Chaetomorpha* sp. as a replacement to fishmeal.

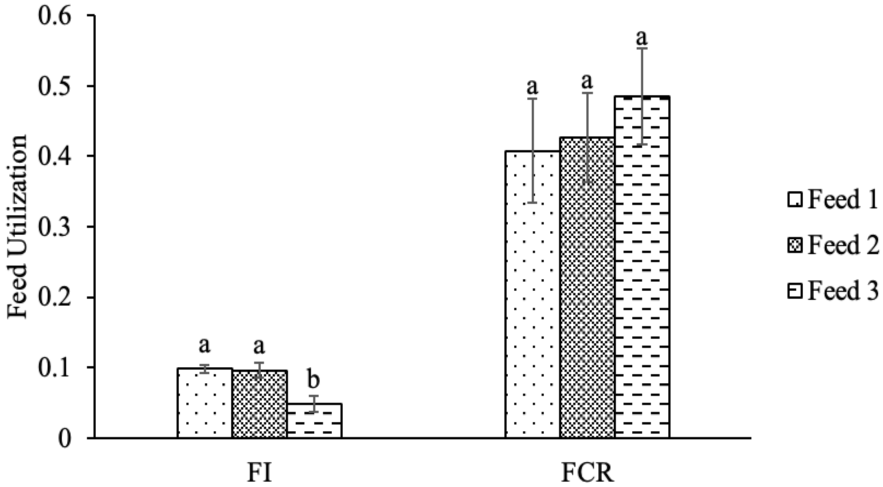

Figure 5. Feed utilization of FGM fry fed with formulated feeds with different levels of *Chaetomorpha* sp. inclusion.

Economic analysis. The cost of feeds and cost-benefit analysis are shown in Tables 4 and 5. The total costs of Feed 1, Feed 2, and Feed 3 were 1.15 kg USD^{-1}, 1.02 kg USD^{-1}, and 0.88 kg $USD^{-1,}$ respectively. The net benefits of Feed 1, Feed 2, and Feed 3 were 0.65 kg USD^{-1}, 0.78 kg USD^{-1}, and 0.92 kg $USD^{-1,}$ respectively. The ECRs of Feed 1, Feed 2, and Feed 3 were 0.47±0.14, 0.44±0.12, and 0.43±0.14, respectively (Table 6).

Table 4

Estimated cost of feed diets in kg USD^{-1}

Feed ingredients	*Feed 1*	*Feed 2*	*Feed 3*
Algal meal (g)	-	-	-
Fish meal (g)	0.27	0.14	-
Starch (g)	0.22	0.22	0.22
Oil (mL)	0.04	0.04	0.04
Corn meal (g)	0.54	0.54	0.54
Wheat flour (g)	0.08	0.08	0.08
Total	1.15	1.02	0.88

Table 5

Cost-benefit analysis of feeds

*Cost benefits analysis (kg USD^{-1})**	*Feed 1*	*Feed 2*	*Feed 3*	*Commercial feeds (World Bank 2024)*
Cost of feed diets	1.15	1.02	0.88	1.80
Net benefits	0.65	0.78	0.92	-

Table 6

Economic analysis for FGM fry fed with formulated experimental feeds

	Feed 1	*Feed 2*	*Feed 3*
Cost of feed diet (kg USD^{-1})*	1.15	1.02	0.88
Feed conversion ratio	0.41 ± 0.07[a]	0.43 ± 0.06[a]	0.49 ± 0.07[a]
ECR	0.47 ± 0.14[a]	0.44 ± 0.12[a]	0.43 ± 0.14[a]

Mean values (±SEM) in the same row sharing different subscripts are significantly different ($p \leq 0.05$); *1$ = 49.61 L.E (local market price in Philippine peso for feed ingredients used for formulating experimental diets in the year 2020).

Discussion. Increasing the production of fisheries is being targeted as a solution to the overpopulation crisis (Sun et al 2010). Developing and expanding fish health can reduce production time and increase productivity (Sattanathan et al 2020). In addition, fish farmers can improve the quality of their feed by modifying the composition based on the nutrients in the feed. The current study showed that fry FGM was not significantly impacted ($p \geq 0.05$) by a feed containing 10% *Chaetomorpha* sp. on growth performance and FCR. However, 0% and 10% of *Chaetomorpha* sp. are significantly different ($p \leq 0.05$) than 20% of *Chaetomorpha* sp. in the survival performance and FI of FGM fry. Despite the lower survival rate of FGM fry observed in this study, it is plausible that the water parameters recorded may have contributed to this outcome. Researchers stated that elevated water temperatures reaching 30°C and pH levels of 8.0 lead to an increased proportion of ammonia in fish culture, thereby reducing the growth, survival and impairing immune function (Hargreaves & Tucker 2004; Randall & Tsui 2002). Additionally, ammonia levels exceeding 0.1 ppm pose significant risks, potentially causing gill damage and respiratory distress, and, with prolonged exposure, can lead to mortality in fish (Hadfield et al 2007; Jin et al 2024). The results indicated that the temperature ranged from 29.52 to 30.02°C, salinity levels varied between 33.85 and 34.11‰, and the pH levels were recorded between 7.94 and 8.14, and the ammonia ranged from 0.03 to 0.06 mg L^{-1}, which may be the reason for the low survival performance of the FGM fry culture. Moreover, nitrite levels exceeding 0.1 mg L^{-1} are considered to cause stress to most Nile tilapia (*Oreochromis niloticus*) fry, with prolonged exposure resulting in high mortality rates (Benli & Köksal 2005; Tanna et al 2020). The present study indicated that the nitrite level varied from 0.04 to 0.05 mg L^{-1}, which may have caused increased mortality in FGM fry cultures. However, other studies stated that the maximum permissible nitrate concentration for carp is 80 mg L^{-1}, whereas, for rainbow trout, it is 20 mg L^{-1} (Ali et al 2020). The nitrate level in the present study was ranging from 10 to 13 mg L^{-1}. Furthermore, as a result, 10% of *Chaetomorpha* sp. can be incorporated into the feed of FGM fry, indicating a reduction in the amount of FM in the feeds, which can be considered cost-effective. Aquaculture researchers have been investigating how filamentous green seaweeds can be used as raw or dried feed to enhance growth and feed efficiency (Cruz-Suárez et al 2010; Siddik et al 2014; Tsutsui et al 2015).

Different levels of algae *Chaetomorpha* sp. have been used in place of FM as a source of protein in a variety of crustaceans and fish, including *P. monodon* and *Labeo rohita* (Tsutsui et al 2015; Sattanathan et al 2020). In addition, 20% *Chaetomorpha* sp. can be incorporated into feed formulations to feed farmed shrimp *P. monodon* postlarvae (Simtoe et al 2023). In *Sciaenops ocellatus* juvenile fish, up to 50% of the diet of soy protein concentrate, fish oil, and fish meal can be substituted with microalgae *Schizochytrium limacinum* and *Arthrospira* sp. meals without compromising the fish's performance (Perez-Velazquez et al 2018). Researchers have found that FM was able to replace 50% of microalgae, *Scenedesmus* and *Chlorella* in the diets of fingerlings of *O. niloticus*, improving growth and feed efficiency (Badwy et al 2008; Raji et al 2019). In addition, *O. niloticus* survival, growth, and feed utilization can be enhanced by feeding them less than 20% red algae, *Gracilaria arcuata.* As a cost-effective alternative, our study found that FM could be replaced in the feed of fry FGM with 10% green algae *Chaetomorpha* sp., improving growth, survival, and feed utilization.

Furthermore, an algal meal (*S. limacinum* and *Arthrospira* sp.) developed for fish farming increased crude protein, crude fat, moisture, gross energy, and ash, thereby enhancing FCR and FI in juvenile red drum *S. ocellatus* (Perez-Velazquez et al 2018). The supplementation of green algae *Chaetomorpha* sp. significantly affects dietary crude fiber, moisture, crude protein, crude fat, and ash. The effects on the chemical compositions of the feeds in the present study showed distinct trends. Moisture increases slightly from Feed 1 (11.83%) to Feed 2 (14.37%) but decreases to 13.63% in Feed 3. Crude protein consistently declines across the feeds, dropping from 20.79% in Feed 1 to 15.65% in Feed 2 and further to 10.27% in Feed 3. The reduction in protein content corresponds with research suggesting that increased moisture levels can reduce the nutrient concentration in fish feeds, particularly affecting protein levels, which are vital for the growth and development of aquaculture species such as tilapia and carp (Iqbal et al 2020). Similarly, crude fat decreases gradually from 6.25% in Feed 1 to 6.03% in Feed 2 and 5.30% in Feed 3. This trend is supported by research suggesting that increased moisture can destabilize fats, leading to reduced fat content in stored fish feeds (Hertrampf & Piedad-Pascual 2012; Kanmani et al 2018). In contrast, ash content increases steadily, from 2.93% in Feed 1 to 4.44% in Feed 2 and 6.04% in Feed 3; this suggests higher mineral content, a conclusion supported by studies that associate elevated ash levels with the addition of more mineral supplements in fish feeds (Deyab & Hussein 2015; Amjad et al 2024). Crude fiber shows a significant rise, from 0.73% in Feed 1 to 2.96% in Feed 2 and reaching 4.71% in Feed 3. This increase aligns with research indicating that the use of cheaper, lower-quality feed ingredients often leads to higher crude fiber content, which can negatively impact feed digestibility and nutrient absorption in fish (Munguti et al 2006; Kassahun et al 2012; Sørensen 2012). Overall, the effects lead to an increase in moisture, ash, and fiber content while reducing crude protein and fat, reflecting a shift toward less energy-dense, higher-fiber feed formulations, which could impact the growth efficiency of fish in culture. Thus, the nutrients in feed can contribute to energy production and the function of living cells by influencing fish metabolism (Krogdahl et al 2005; Ndome et al 2010). Additionally, feed utilization, such as FCR and FI, is an effective parameter in reducing the cost of production of fish farming (Sattanathan et al 2020). In this study, FI was improved with the addition of 10% *Chaetomorpha* sp., whereas FCR was not affected by different concentrations of *Chaetomorpha* sp. Other findings stated that different levels of algal meal did not affect the feed utilization for red drum *S. ocellatus* and *O. niloticus* (Perez-Velazquez et al 2018; Younis et al 2018).

Fish production is hindered by the increased cost of feed, which is considered a major factor limiting profitability in the industry. It has been an ongoing goal of research to develop an alternative ingredient that reduces the cost of fish feed primarily because of the high cost of FM (Ansari et al 2021; Takakuwa et al 2022). This study showed that up to 10% replacement of FM with AM improves the FCR. A similar tendency was observed for values of the ECR as well as the cost of feed diets (Table 3). It was found that the percentage of cost reduction between Feed 1 and Feed 2 was 11.30%, while the reduction between Feed 2 and Feed 3 was 13.73%. This suggests that a higher concentration of *Chaetomorpha* sp. led to higher cost savings in the feed diets, indicating that incorporating *Chaetomorpha* sp. into feed formulations is a more cost-effective approach. Studies have shown that algae like *Chaetomorpha* sp. are rich in essential nutrients and can serve as an alternative protein source in aquaculture feeds, reducing the reliance on expensive fishmeal and soybean meal, which are often the primary cost drivers in feed production (Rajauria 2015; Eroldoğan et al 2023). Additionally, algae have been shown to enhance feed conversion efficiency and lower production costs, all while maintaining or even improving the growth performance of cultured species (Guedes & Malcata 2012). The use of *Chaetomorpha* sp. in feed formulations has been particularly noted for its potential to lower feed costs while maintaining a balanced nutritional profile for aquaculture species. Moreover, the formulated feeds using FM replacements of 10% or 20% with AM were the cheapest and are recommended for cultivating FGM fry. Several studies have demonstrated that FM can be substituted with more affordable plant-based or animal-based alternatives to reduce the cost of fish and crustacean feeds (Badwy et al 2008; Tsutsui et al 2015; Perez-Velazquez et al 2018; Younis et al 2018; Sattanathan et al 2020; Hairol et al 2022).

Conclusions. In a nutshell, algal meal derived from the alga *Chaetomorpha* sp. can replace fish meal in the diet formulations of flathead grey mullet *Mugil cephalus* fry. Consequently, the feed which replaces 10% of the FM with AM gives signifcant growth, survival, and feed utilization as the FM-based control diet. Considering their cost-effectiveness, algal meals derived from *Chaetomorpha* sp. are presently cheaper than fish meals, thus resulting in reduced fish production costs. Economic analysis is crucial for stakeholders, including fish farmers, feed manufacturers, and policymakers, as it allows them to evaluate the financial implications of incorporating algal meal into feed formulations. By understanding the cost-benefit ratio and potential savings associated with using algal meal, stakeholders can make informed decisions that enhance profitability while promoting sustainable practices in aquaculture. Additionally, a thorough economic analysis can identify optimal formulations and feeding strategies, facilitating the successful integration of alternative protein sources and ensuring food security in a growing aquaculture industry. However, further investigation is required to optimize the level of *Chaetomorpha* sp. used in the diets of Flathead grey mullet fry to maximize growth and minimize costs effectively.

Acknowledgements. The authors are grateful to Mindanao State University-Tawi-Tawi College of Technology and Oceanography, College of Fisheries, Multi-species hatchery.

Conflict of interest. There are no conflicts of interest or personal relationships that may appear to influence the authors' work.

References

Ali A., Moustafa Y. T. A., El-Said S. M. A., 2020 Evaluating the influence of different water sources on water quality, survival and growth rates of Nile tilapia (*Oreochomis niloticus*) larvae in tilapia hatcheries. Egyptian Journal for Aquaculture 10(1):45-64.

Amjad M., Hussain S. M., Ali S., Sarker P. K., Al-Ghanim K. A., Nazish N., 2024 Biochar utilization for aquaculture sustainability: effect on growth performance, nutrient digestibility, body composition, hematology and mineral status of *Ctenopharyngodon idella*. Aquaculture Reports 38:102327.

Ansari F. A., Guldhe A., Gupta S. K., Rawat I., Bux F., 2021 Improving the feasibility of aquaculture feed by using microalgae. Environmental Science and Pollution Research 28(32):43234-43257.

Badwy T. M., Ibrahim E. M., Zeinhom M. M., 2008 Partial replacement of fishmeal with dried microalga (*Chlorell*a spp. and *Scenedesmus* spp.) in Nile tilapia (*Oreochromis niloticus*) diets. 8th International Symposium on Tilapia in Aquaculture, pp. 801-811.

Benli A. Ç. K., Köksal G., 2005 The acute toxicity of ammonia on tilapia (*Oreochromis niloticus* L.) larvae and fingerlings. Turkish Journal of Veterinary and Animal Sciences 29(2):339-344.

Biswas G., De D., Thirunavukkarasu A. R., Natarajan M., Sundaray J. K., Kailasam M., Kumar P., Ghoshal T. K., Ponniah A. G., Sarkar A., 2012 Effects of stocking density, feeding, fertilization and combined fertilization-feeding on the performances of striped grey mullet (*Mugil cephalus* L.) fingerlings in brackishwater pond rearing systems. Aquaculture 338-341:284-292.

Cruz-Suárez L. E., León A., Peña-Rodríguez A., Rodríguez-Peña G., Moll B., Ricque-Marie D., 2010 Shrimp/*Ulva* co-culture: a sustainable alternative to diminish the need for artificial feed and improve shrimp quality. Aquaculture 301(1-4):64-68.

Deyab E. S. D. M. S., Hussein E. E. S. M., 2015 Effects of different feeding rates on growth performance and body composition of red tilapia, *Oreochromis mossambiquse* x *O. niloticus*, fingerlings. International Journal of Aquaculture 5(12):1-7.

Elhetawy A. I. G., El-Dahhar A. A., Elebiary E. H., Abo El-Wafa M. A., Lotfy A. M., Emelianova N., 2021 Effect of biofloc system at different salinities and crude protein levels on water quality, growth performance, and survival rate of flathead grey mullet (*Mugil cephalus*). Egyptian Journal for Aquaculture 11(1):41-67.

Eroldoğan O. T., Glencross B., Novoveska L., Gaudêncio S. P., Rinkevich B., Varese G. C., Carvalho M. D. F., Tasdemir D., Safarik I., Nielsen S. L., Rebours C., Lada L. B., Robbens J., Strode E., Haznedaroğlu B. Z., Kotta J., Evliyaoğlu E., Oliveira J., Girão M., Vasquez M. I., Čabarkapa I., Rakita S., Klun K., Rotter A., 2023 From the sea to aquafeed: a perspective overview. Reviews in Aquaculture 15(3):1028-1057.

FAO, 2022 The state of world fisheries and aquaculture 2022 - towards blue transformation. FAO, Rome, 266 pp.

Fleurence J., Morançais M., Dumay J., 2018 Seaweed proteins. In: Proteins in food processing. 2nd edition. Yada R. Y. (ed), Woodhead Publishing pp. 245-262.

Gazali M., Zamani N. P., Nurjanah, 2019 The potency of green algae *Chaetomorpha crassa* Agardh as antioxidant agent from the coastal of Lhok Bubon, West Aceh. IOP Conference Series: Earth and Environmental Science 278(1):012029.

Genovese G., Leitner S., Minicante S. A., Lass-Flörl C., 2013 The Mediterranean red alga *Asparagopsis taxiformis* has antifungal activity against *Aspergillus* species. Mycoses 56(5):516-519.

Gephart J. A., Golden C. D., Asche F., Belton B., Brugere C., Froehlich H. E., Fry J. P., Halpern B. S., Hicks C. C., Jones R. C., Klinger D. H., Little D. C., McCauley D. J., Thilsted S. H., Troell M., Allison E. H., 2021 Scenarios for global aquaculture and its role in human nutrition. Review in Fisheries Science and Aquaculture 29(1):122-138.

Gisbert E., Mozanzadeh M. T., Kotzamanis Y., Estévez A., 2016 Weaning wild flathead grey mullet (*Mugil cephalus*) fry with diets with different levels of fish meal substitution. Aquaculture 462:92-100.

Gokulakrishnan S., Raja K., Sattanathan G., Subramanian J., 2015 Proximate composition of bio potential seaweeds from Mandapam South East Coast of India. International Letters of Natural Sciences 45:49-55.

Guedes A. C., Malcata F. X., 2012 Nutritional value and uses of microalgae in aquaculture. In: Aquaculture. Muchlisin A. Z. (ed), InTech Open, pp. 59-78.
Hadfield C. A., Whitaker B. R., Clayton L. A., 2007 Emergency and critical care of fish. Veterinary Clinics of North America: Exotic Animal Practice 10(2):647-675.
Hairol M. D., Nian C. T., Imlani A. H., Tikmasan J. A., Sarri J. H., 2022 Effects of crab shellmeal inclusions to fishmeal replacement on the survival, growth, and feed utilization of mangrove crab *Scylla serrata* (Forsskal 1775). Yuzuncu Yil University Journal of Agricultural Sciences 32(4):714-726.
Hargreaves J. A., Tucker C. S., 2004 Managing ammonia in fish ponds. SRAC Publication No. 4603, 8 pp.
Hertrampf J. W., Piedad-Pascual F., 2012 Handbook on ingredients for aquaculture feeds. Springer Science & Business Media, 573 pp.
Hien T. T. T., Trung N. H. D., Tâm B. M., Chau V. M. Q., Huy N. H., Lee C. M., Bengtson D. A., 2016 Replacement of freshwater small-size fish by formulated feed in snakehead (*Channa striata*) aquaculture: experimental and commercial-scale pond trials, with economic analysis. Aquaculture Reports 4:42-47.
Iqbal R., Naeem M., Masud S., Ishtiaq A., 2020 Effect of graded dietary protein levels on body composition parameters of hybrid (*Labeo rohita* ♀ and *Catla catla* ♂) from Pakistan. Sarhad Journal of Agriculture 36(2):548-558
Jin J. H., Amenyogbe E., Yang Y., Wang Z. L., Lu Y., Xie R. T., Droepeno E. K., Huang J. S., 2024 Effects of ammonia nitrogen stress on the physiological, biochemical, and metabolic levels of the gill tissue of juvenile four-finger threadfin (*Eleutheronema tetradactylum*). Aquatic Toxicology 274:107049.
Kanmani N., Romano N., Ebrahimi M., Amin S. M. N., Kamarudin M. S., Karami A., Kumar V., 2018 Improvement of feed pellet characteristics by dietary pre-gelatinized starch and their subsequent effects on growth and physiology in tilapia. Food Chemistry 239:1037-1046.
Kassahun A., Waidbacher H., Zollitsch W., 2012 Proximate composition of selected potential feedstuffs for small-scale aquaculture in Ethiopia. Livestock Research for Rural Development 24(6):106.
Klein B., Davis R., 2023 Algal biomass production via open pond algae farm cultivation: 2022 state of technology and future research. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5100-85661, 27 pp.
Krogdahl A., Hemre G. I., Mommsen T. P., 2005 Carbohydrates in fish nutrition: digestion and absorption in postlarval stages. Aquaculture Nutrition 11(2):103-122.
Maundu A. M., 2020 Digestibility, growth and economic performance of Nile tilapia (*Oreochromis niloticus*) fed on a mixture of plant protein diets in cages. PhD dissertation, Kenyatta University, Nairobi, Kenya, 116 pp.
Mondal A., Chakravortty D., Mandal S., Bhattacharyya S. B., Mitra A., 2015 Feeding ecology and prey preference of grey mullet, *Mugil cephalus* (Linnaeus, 1758) in extensive brackish water farming system. Journal of Marine Science Research and Development 6(2):1000178.
Munguti J. M., Liti D. M., Waidbacher H., Straif M., Zollitsch W., 2006 Proximate composition of selected potential feedstuffs for Nile tilapia (*Oreochromis niloticus* Linnaeus) production in Kenya. Die Bodenkultur Journal of Land Management Food and Environment 57(3):131-141.
Mutia G. M., 2024 Effects of *Ulva rigida* (C. Agardh) and *Chaetomorpha crassa* (C. Agardh) as feed supplements on growth performance and body composition of Nile tilapia *Oreochromis niloticus* (Linnaeus) fingerlings. IOSR Journal of Agriculture and Veterinary Science 17(7):13-19.
Ndome C., Oriakpono O., Ogar A., 2010 Proximate composition and nutritional values of some commonly consumed fishes from the Cross River Estuary. Tropical Freshwater Biology 19(1):11-18.
Perez-Velazquez M., Gatlin III D. M., González-Félix M. L., García-Ortega A., 2018 Partial replacement of fishmeal and fish oil by algal meals in diets of red drum *Sciaenops ocellatus*. Aquaculture 487:41-50.

Perez-Velazquez M., Gatlin III D. M., González-Félix M. L., García-Ortega A., de Cruz C. R., Juárez-Gómez M. L., Chen K., 2019 Effect of fishmeal and fish oil replacement by algal meals on biological performance and fatty acid profile of hybrid striped bass (*Morone crhysops* ♀ × *M. saxatilis* ♂). Aquaculture 507:83-90.

Radhakrishnan S., Saravana B. P., Seenivasan C., Muralisankar T., 2015 Effect of dietary replacement of fishmeal with *Chlorella vulgaris* on growth performance, energy utilization and digestive enzymes in *Macrobrachium rosenbergii* postlarvae. International Journal of Fisheries and Aquaculture 7(5):62-70.

Rajauria G., 2015 Seaweeds: a sustainable feed source for livestock and aquaculture. In: Seaweed sustainability. Food and non-food applications. Tiwari B. K., Troy D. J. (eds), Academic Press, pp. 389-420.

Raji A. A., Junaid O. Q., Milow P., Taufek N. M., Fada A. M., Kolawole A. A., Alias Z., Razak S. A., 2019 Partial replacement of fishmeal with *Spirulina platensis* and *Chlorella vulgaris* and its effect on growth and body composition of African catfish *Clarias gariepinus* (Burchell 1822). Indian Journal of Fisheries 66(4):100-111.

Randall D. J., Tsui T. K. N., 2002 Ammonia toxicity in fish. Marine Pollution Bulletin 45(1-12):17-23.

Sattanathan G., Palanisamy T., Padmapriya S., Arumugam V. A., Park S., Kim I. H., Balasubramanian B., 2020 Influences of dietary inclusion of algae *Chaetomorpha aerea* enhanced growth performance, immunity, haematological response and disease resistance of *Labeo rohita* challenged with *Aeromonas hydrophila*. Aquaculture Reports 17:100353.

Shafique L., Abdel-Latif H. M. R., Hassan F. U., Alagawany M., Naiel M. A. E., Dawood M. A. O., Yilmaz S., Liu Q., 2021 The feasibility of using yellow mealworms (*Tenebrio molitor*): towards a sustainable aquafeed industry. Animals 11(3):811.

Sharawy Z. Z., Ashour M., Abbas E., Ashry O., Helal M., Nazmi H., Kelany M., Kamel A., Hassaan M., Rossi Jr. W., El-Haroun E., Goda A., 2020 Effects of dietary marine microalgae, *Tetraselmis suecica*, on production, gene expression, protein markers and bacterial count of Pacific white shrimp *Litopenaeus vannamei*. Aquaculture Research 51(6):2216-2228.

Siddik M. A. B., Nahar A. Rahman M. M., Anh N. T. N., Nevejan N., Bossier P., 2014 Gut weed, *Enteromorpha* sp. as a partial replacement for commercial feed in Nile tilapia (*Oreochromis niloticus*) culture. World Journal of Fish and Marine Sciences 6(3): 267-274.

Simtoe A. P., Luvanga S. A., Lugendo B. R., 2023 Partial replacement of fishmeal with *Chaetomorpha* algae improves feed utilization, survival, biochemical composition and fatty acids profile of farmed shrimp *Penaeus monodon* post larvae. Aquaculture International 31(3):1375-1388.

Sørensen M., 2012 A review of the effects of ingredient composition and processing conditions on the physical qualities of extruded high-energy fish feed as measured by prevailing methods. Aquaculture Nutrition 18(3):233-248.

Sun Y. Z., Yang H. L., Ma R. L., Lin W. Y., 2010 Probiotic applications of two dominant gut *Bacillus* strains with antagonistic activity improved the growth performance and immune responses of grouper *Epinephelus coioides*. Fish and Shellfish Immunology 29(5):803-809.

Tacon A. G. J., Hasan M. R., Metian M., 2011 Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects. FAO Fisheries and Aquaculture Technical Paper 564, FAO, Rome, 87 pp.

Takakuwa F., Sato H., Mineyama N., Yamada S., Biswas A., Tanaka H., 2022 Bioavailability of porcine blood meal as a fish meal substitute in the diet for red sea bream (*Pagrus major*, Temminck & Schlegel) fingerling. Aquaculture Research 53(13):4616-4626.

Tanna K., Bhavsar B., Mankad A., 2020 Aquatic toxicity impacts on behaviour and survival of freshwater fish: a review. International Journal of Fisheries and Aquatic Studies 8(3):235-243.

Tsutsui I., Songphatkaew J., Meeanan C., Aue-umneoy D., Sukchai H., Pinphoo P., Klomkling S., Ganmanee M., Sudo H., Hamano K., 2015 Co-culture with *Chaetomorpha* sp. enhanced growth performance and reduced feed conversion ratio of the giant tiger prawn, *Penaeus monodon*. International Aquatic Research 7(3): 193-199.
Welker T. L., Lim C., Barrows F. T., Liu K., 2014 Use of distiller's dried grains with solubles (DDGS) in rainbow trout feeds. Animal Feed Science and Technology 195: 47-57.
Whitfield A. K., Panfili J., Durand J. D., 2012 A global review of the cosmopolitan flathead mullet *Mugil cephalus* Linnaeus 1758 (Teleostei: Mugilidae), with emphasis on the biology, genetics, ecology and fisheries aspects of this apparent species complex. Reviews in Fish Biology and Fisheries 22(3):641-681.
Wiatrowski M., Klein B. C., Davis R. W., Quiroz-Arita C., Tan E. C. D., Hunt R. W., Davis R. E., 2022 Techno-economic assessment for the production of algal fuels and value-added products: opportunities for high-protein microalgae conversion. Biotechnology for Biofuels and Bioproducts 15(1):8.
World Bank, 2024 World Bank Commodity price data (the pink sheet). 3 pp.
Younis E. S. M., Al-Quffail A. S., Al-Asgah N. A., Abdel-Warith A. W. A., Al-Hafedh Y. S., 2018 Effect of dietary fish meal replacement by red algae, *Gracilaria arcuata*, on growth performance and body composition of Nile tilapia *Oreochromis niloticus*. Saudi Journal of Biological Sciences 25(2):198-203.

Received: 15 January 2026. Accepted: 12 February 2026. Published online: 13 March 2026.
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How to cite this article:
Maribao I. P., Jumsali M. H., Sarri J. H., Nian C. T., Ensano F. N. T., Jamil W. M., Robles R. J. F., Hairol M. D., 2026 Growth performance and economic analysis of incorporating algal meal in feed formulation of flathead grey mullet fry. AACL Bioflux 19(2):482-495.