

Original Research Articles

Assessment of Indigenous Feed Ingredients on Growth and Feed Utilization Efficiency in Juvenile Milkfish (*Chanos chanos* Forsskål, 1775)

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This study aimed to assess the feasibility of utilizing indigenous feed ingredients for milkfish (*Chanos chanos* Forsskål 1775) aquaculture. Nine different feed treatments were tested: taro, golden apple snail, azolla plant, blood meal, cacao pod, banana stem, copra meal, soybean meal, and a control. We used 15 juvenile milkfish (initial weights=6.4-7.4 g; initial lengths=5.3-5.7 cm) cultured in 80 L tanks and replicated three times to assess their growth and feed utilization. After 60 days of culture, copra meal and Azolla attained 23.0 g and 21.8 g, which were higher compared to the other treatments. This was followed by taro (18.9 g), bloodmeal (18.4 g), golden apple snail (18.2 g), control (18.2 g), cacao pod (18.2 g), soybean treatments (17.5 g), and lastly banana stem (16.1 g). Comparison of the initial length and weight of the treatments versus their final values during the 60 days of culture showed differences (length: $t=20.0$, $p=0.0001$, $df=16$; weight: $t=16.5$, $p=0.0001$, $df=16$) but none between the nine treatments ($p>0.05$). In terms of average daily weight gain, copra meal gained faster (0.34 g), followed by Azolla (0.24 g), and then the control (0.22 g) and bloodmeal (0.19 g) with banana stem the last (0.15 g). While in terms of feed conversion ratio (FCR), copra meal (1.1), azolla (1.3), taro (1.5) and the control (1.5) had the lowest FCR values; banana stem (1.9) and soybean meal treatments (2.0) had the highest. Fulton's condition factor showed that these four treatments (taro=1; Azolla=1.2; copra meal=1.2; control=1.2) were closest to 1, signifying a healthy condition. The gonadosomatic index (GSI=0.005) and hepatosomatic index (HSI=0.03) values were consistent in the various treatments, showing no adverse effects suffered during the period of culture. The alternative feeds can be used in milkfish aquaculture to reduce the cost of operation.

INTRODUCTION

In the Philippines, milkfish (*Chanos chanos*, Forsskål 1775), locally called bangus, is one of the most consumed fish from aquaculture with a production of 355,425.87 tons in 2023.¹ Given the increasing volume and value of milkfish production in the Philippines, the importance of this industry cannot be understated as it generates, on average, about Php 2.8 million in gross revenue for two to three cages in a year. Thus, it has a high value in demand throughout the year and helps address the country's need for fish food protein. As such, increasing government investments and creating livelihood in coastal communities will be necessary to

maintain and sustain the milkfish industry, making it beneficial for the fishing and aqua-farming communities.²

Recently, the BFAR Region XI reported the fisheries' situation regarding milkfish production within the Davao region as of 2023. According to the report, the volume of output of milkfish is decreasing reaching a total production of 19,645.53 tons in 2023.³ Moreover, the total milkfish production in Davao Oriental was only 240.23 tons. This marked a significant decrease compared to previous years, with a 54 % drop from 2022 and an 81.28 % decrease from 2021.⁴ The inadequate number of milkfish production can be attributed to several factors such as environmental changes, disasters, pandemic and lack of financial access.⁵

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Moreover, the growth of the milkfish industry was constrained by the farmer's limited access to infrastructure and technologies throughout the production process, along with poor market connections and high capital needs.^{6,7} Of all input costs, the feed cost is 80 % of the total operation cost of a milkfish aquaculture farm.⁸ To offset this problem, a key answer lies in the use of waste materials as feed components, locally available and considered as feed sources.^{9,10} Locally available agricultural wastes such as cacao pods, and banana wastes have demonstrated potential as possible nutrient feed sources for livestock. Unfortunately, cacao pods, and banana stem have never been tested on juvenile milkfish for growth experiments or as feed components making this as a timely and relevant experiment given that this remains largely unexplored¹⁰

The development of locally sourced feeds from indigenous sources could buffer the high cost of feeds, spur the feed-making industry, lessen dependence on imported inputs, and put the industry on a sustainable trajectory. Moreover, there is a lack of research on sustainable and cost-effective feed alternatives using available agricultural wastes.^{7,8} Agricultural wastes are a growing concern due to environmental challenges regarding disposal and can be repurposed for energy and chemicals.¹¹ Agricultural wastes such as cacao pod husk, and banana stem represent a significant but often underutilized resource. In pursuing sustainable farming methods, new ideas are arising to handle waste and improve feed efficiency. The husk of cacao can be utilized as compost or food for livestock. Cacao pod husks contain high amounts of dietary fiber and phenolic compounds, showing potential as a natural source of nutrients and functional properties.¹² According to Philippine Statistics Authority,¹³ cacao production in the Philippines has improved to 2,350 tons (4.1%) from 2,260 tons recorded output in April 2022 to June 2022. Additionally, Davao Region remains as the top producer of cacao in the country with 1,670 tons (71.2 %) share to the country's total cacao production in the same period.

On the other hand, banana stem, the stalk of a banana plant, contains bioactive compounds with strong antioxidant properties and health benefits that can be considered as a functional food.¹⁴ Banana stems and leaves can be used for fertilization, fodder, energy, fiber, coloring, flavoring, livestock feed, and more.¹⁵ According to the report of the Philippine Statistics Authority,¹⁶ banana production in the Philippines was estimated to be 2.27 million tons. The said report also stated that Davao Region was the top banana producer with 868,190 tons (38.3%) share of the total production in the same period.

Another possible alternative feed source for fish is Azolla which has been used as a feedstock for other animals,¹⁷ due to its high protein, fat, amino acids, and vitamin content which is beneficial for animal feed.^{18,19} Azolla can be an effective substitute source of protein compared to expensive sources like fish oil and fish meal depending on the feeding habits of the fish species.²⁰ Like the previous plant sources, taro (*Colocasia esculenta*) is a cost-effective, nutritious root crop rich in carbohydrates, fiber, vitamins, and minerals but underutilized.²¹ Taro corms contain bioactive compounds

that fight cancer, carcinogens, inflammation, and oxidative stress, while regulating metabolism and boosting immune response.²² Taro is crucial for food security, cash crops, and rural development. Taro production in the Philippines is low and declining at 107,422.18 tons.²³

Another possible source of protein is the golden apple snail (*Pomacea canaliculata*), which is abundant in many rice paddies in the Philippines and valuable for its high calcium and protein content making it a viable source of protein.²⁴ In contrast to the above sources, copra meal, soybean meal, and blood meal are well-known and used in the feed industry which offers the necessary balanced nutrition required by cultivated fish. Copra meal and soybean meal are suitable protein sources as fish feeds because of their high nutritional crude protein value e.g. 21.7% for copra meal²⁵ and 40% for soybean meal.²⁶ Utilizing copra meal as a substitute feed ingredient provides economic benefits. It is a readily available resource that offers a low-cost alternative source of protein and energy.²⁷ According to Philippine Statistics Authority,¹³ the coconut production in the Philippines reached 14.89 million metric tons with 3.41 million tons of coconut coming from the Davao region.

According to Bai et al.,²⁸ soybean meal, a crucial plant protein source in animal feeds, is a valuable ingredient that can partially substitute fish meal in fish feeds. The protein quality, chemical composition, and nutritive value of commercial soybean meal (SBM) can vary due to factors such as seed variety, growing conditions, harvesting, and storage, as well as the oil extraction method.²⁹ Soybean production in the Philippines is estimated to be around 2,000 to 3,000 tons per year, utilized entirely for food.³⁰ In Mindanao, Caraga region is the hub of soybean production, with 350 hectares yielding an annual estimate of around 50% of the total volume of soybean produced in the country.³¹ On the other hand, a blood meal is a dry product made from clean, fresh animal blood (chicken and cow), excluding extraneous materials.³² A blood meal is a good feed for tilapia and other fish species, improving growth and nutrition at 10 % or lower levels in the diet.^{9,33}

Integrating these various feed sources for aquaculture use can improve sustainability, efficiency, resource optimization, and reduce costs.⁸ For this reason, we tested the raw materials which can be useful in feed-making. The use of indigenous and available materials will help reduce agricultural wastes, alleviate greenhouse gas emissions on the farm, and implement a circular economy. Likewise, the circular economy benefits the climate, biodiversity, and social needs of the community while also generating wealth and increasing sustainability on the farm.³⁴ Thus, this study examined and developed locally available feed materials for the evaluation of the growth response of juvenile milkfish in experimental laboratory conditions.

Table 1. Composition (g/100g) of control diet

Ingredients	g/100 g dry weight
Fishmeal	19.78
Soybean meal (SBM)	19.66
Wheat pollard	23.00
Rice bran	23.00
Bread flour	5.00
Soybean oil	2.00
Cod liver oil	2.00
Soy lecithin	1.00
Vitamins	2.00
Minerals	2.00

MATERIALS AND METHODS

FEED DEVELOPMENT AND EXPERIMENTAL PROCEDURES FOR MILKFISH JUVENILES TANK-BASED CULTURE

The study on feeds necessitated a thorough analysis of the raw materials used in the experiment. This involved nutrient analysis, incorporating secondary data to assess their composition, particularly crude protein and carbohydrates, as well as their prior application in aquaculture. For the experiment, all major nutrient components of the diet were based on the milkfish formulated diet of Llamag and Serrano.³⁵ The control diet was also based on this composition shown in [Table 1](#). The experimental setup was completely randomized and replicated three times in a recirculating 80 L tank setup. So, there were nine treatments comprised of fishmeal and non-fishmeal-based diets in 27 tanks. The set-up contained the following treatments e.g. golden apple snail (*Pomacea canaliculata*), azolla plant (*Azolla pinnata*), blood meal, cacao pod (*Theobroma cacao*), banana stem (*Musa paradisiaca x balbacciana*), copra meal (*Cocos nucifera*), soybean meal (*Glycine max*), taro (*Colocasia esculenta*), and control.

The experiment utilized locally available ingredients as an alternative to commercial feed components, ensuring a cost-effective and sustainable approach to fish nutrition. All ingredients were procured locally or within the Davao region to formulate the diet. Overall, there were nine treatments where 15 juvenile milkfish (N=405) were distributed, and their growth responses, feed utilization efficiency, hepatosomatic index, and gonadosomatic indices were measured and assessed. The milkfish were fed three times daily (0800, 1000, and 1600) based on a developed 100-gram diet and fed 25% only in the morning. The decision to allocate only 25% of the total daily feed at 08:00 AM was based on juvenile milkfish's feeding behavior, digestion efficiency, and water quality management. Fish have lower metabolic activity in the early morning, so limiting feed intake prevents waste and ensures better digestion.³⁶ Feeding too much during early morning may lead to uneaten feed which may accumulate, negatively impacting water quality. The remaining 75% of the feed was given later (10:00 AM and 4:00 PM) at an equal proportion of feeding when milkfish

exhibit peak feeding activity. This approach optimizes feed utilization, promotes uniform growth, and maintains water quality.³⁷

The diet was adjusted every two weeks based on the body weight of the fish sampled from the tank. The diet was adjusted based on the average body weight (ABW) of the fish, which was determined by sampling five fish per tank every 15 days. These sampled fish were weighed, and the ABW was used to recalculate the feeding rate, ensuring that the fish received an appropriate amount of feed. Moreover, the amount of feeds per day was adjusted every 15 days based on the average body weight (ABW) of the fish during each sampling period. The daily feeding ration (DFR) was calculated as follows: $DFR = \text{Total number of fish (pcs)} \times \text{ABW (g)} \times \text{feeding rate (\%)}$.

If mortality occurred during the 60-day experiment, the total number of fish in each tank was reassessed, and the feed allocation was adjusted accordingly. The ABW was recalculated using only the surviving fish, and the feeding ration was proportionally reduced to prevent overfeeding and maintain water quality. This approach ensured that the remaining fish received adequate nutrition while minimizing excess feed accumulation. Water parameters were monitored weekly, including water temperature ($^{\circ}\text{C}$), pH, and dissolved oxygen (DO) level. These parameters were maintained within the optimal range for milkfish growth to ensure experimental consistency. Water change was done at 60% by volume every three days to avoid sudden change of water temperature which can affect the health of juvenile milkfish.

We used a filtration system and water circulation to ensure the water quality of each tank. The weight and length of juvenile milkfish were measured every 15 days. Data were collected from all fish in each tank consisting of five samples from each tank. In this study, fish were randomly selected from each treatment group to track growth trends while minimizing handling stress. Measuring all surviving fish was impractical due to potential stress and health risks. The selection process ensured that data reflected the overall population rather than specific individuals. To assess correlations between survival rate and growth performance, key metrics such as weight gain, feed conversion ratio (FCR), and specific growth rate (SGR) were analyzed using statistical methods. Environmental factors like water quality and stocking density were also considered. After measurement, fish were returned to the tank to minimize disruption while maintaining data accuracy and good handling.

The treatments used in the experiment manipulated the proportion of protein content diet by replacing or reducing fishmeal component of the control diet and replaced it with 50% protein content coming from bloodmeal, cacao pod, banana stem, copra, azolla, soya, and golden apple snail. Soybean meal, wheat pollard and rice bran were adjusted to balance the nutrient levels of the experimental diets. The dry ingredients were thoroughly mixed before adding lecithin, soybean oil, and cod liver oil. Water was then added to the mixture at the ratio of 3:1 and thoroughly mixed. The mixtures were pelletized using a laboratory pel-

Table 2. Nutritive value of the nine dietary treatments based on the laboratory results*.

IDENTIFICATION	% Crude Protein	% Crude Fiber	% Crude Fat	% Ash	% Moisture	% Calcium	% Phosphorus	% Salt
Taro-based diet	18.8	2.7	3.0	5.3	12.1	0.32	0.6	0.7
Formulated diet (Fishmeal-based diet)	39.4	4.4	5.3	12.4	9.3	2.3	1.5	0.9
Azolla-based diet	31.5	5.4	2.6	12.4	14.9	0.5	0.8	2.0
Banana stem-based diet	22.8	5.3	3.1	8.1	10.5	0.7	0.8	0.7
Cacao pod-based diet	25.1	5.4	2.4	5.2	12.0	0.3	0.6	0.4
Golden apple snail meal-based diet	27.7	1.8	0.9	15.9	10.1	1.9	0.6	0.3
Copra meal-based diet	26.1	6.8	2.8	7.3	11.6	1.06	0.9	0.4
Soybean meal-based diet	34.7	2.8	3.3	5.7	11.1	0.7	0.71	0.4
Blood meal-based diet	24.5	2.2	1.3	2.8	42.3	0.1	0.4	0.4

* Analyzed actual values from the Feed Analytical Laboratory (FCAL), Department of Agriculture-Region XI, Davao City, Philippines

let extruder. The pelletized feeds were then sundried and kept at room temperature in clean vessels for immediate use. A sample of the feeds used (200g) were subjected to proximate analysis of crude fat, crude protein, ash, moisture content, salt, and magnesium (Table 2). For every 15 days, a sample of fish from each tank was weighed and measured individually to measure their growth and adjust the feeding rates. At the end of the experiment, three triplicate samples of fish from each treatment were used for liver and gonad samples for the hepato- and gonadosomatic indices.

CHEMICAL ANALYSIS

TEST METHODS TO ANALYZE MOISTURE, PROTEIN, LIPID, FIBER, AND ASH

Moisture, crude protein, crude fat, crude fiber, ash, and nitrogen-free extract (NFE) are the key feed components measured in this research. The first test was moisture content, as excess moisture can cause mold growth and feed deterioration. Moisture content was the first metric measured. High moisture levels in feed can increase mold growth and spoiling, shortening the duration of its use. The moisture was evaporated from the feed sample by drying it in an oven at 105°C, and the weight loss was then utilized to quantify the moisture content.

The Kjeldahl method determines the crude protein level, which is critical for animal growth, muscle development, and enzymatic functions. Sulfuric acid is used to digest the material, turning nitrogen into ammonium sulfate. After measuring the nitrogen content, the crude protein is estimated using a conversion factor. Soxhlet extraction is used to determine crude fat content by dissolving and removing fat from the feed using a solvent such as petroleum.

Crude fiber analysis quantifies the feed's non-digestible components, which primarily include cellulose, hemicellulose, and lignin. The ash content of the feed indicates its

entire mineral substance. All organic material is burnt out by incineration in a muffle furnace at 550-600°C, leaving just the inorganic residue. The amount of ash is an approximate measure of the total mineral presence in the feed, including the minerals calcium, phosphorus, and trace elements required for bone health, enzyme activity, and various physiological functions. The Nitrogen-Free Extract (NFE) is calculated indirectly by subtracting moisture, crude protein, crude fat, crude fiber, and ash from 100%. It represents the quickly digested carbohydrate part, which contains sugars and starches and provides animals with a rapid source of energy.

DATA ANALYSIS

Data analysis of the feed experiments, and comparison of various treatments in terms of measured growth, size, and weight was done using one-way ANOVA and *t*-test was used to compare the initial length and weight data to the final length and weight data by pooling these data from the various treatments. To do that, weight and length data was first tested for normal distribution, and if this violated the assumptions for ANOVA, then this was converted using $\log_{10}$ for both the length and weight data and then tested again for normal distribution using Kolmogorov-Smirnov test (for weight data: $KS=0.195$, $p<0.010$ and for length data: $KS=0.148$, $p\leq 0.020$) and equal variances using Bartlett's test (for weight data: $p=0.28$ and for length data: $p=0.171$).

Other remaining growth variables were compared using Pearson correlation. Calculations included individual fish in terms of final body weight e.g., weight of fish/length of fish $\times 100$ for individual condition factor (CF, g/cm^3), individual body weight (FBW), and length of fish, hepato-somatic index (HIS) (liver wet weight (g)/live body weight (g)) and Gonadosomatic index (e.g., gonad weight (g)/live body weight (g)). Moreover, growth was calculated based on

weight gain e.g., final body weight/number of fish-initial body weight/number of fish. While feed conversion ratio (FCR) will be calculated based on dry feed intake/weight gain of fish sampled. Protein efficiency ratio (PER) was calculated based on weight gain (g)/total protein intake (g) while survival was computed based on the final number of fish/initial number of fish $\times 100$.

KEY METRICS FOR EVALUATING MILKFISH GROWTH AND FEED UTILIZATION EFFICIENCY

Several critical metrics are involved in assessing the growth, feed efficiency, and overall production performance of milkfish in aquaculture. These indicators help optimize feeding strategies, enhance productivity, and ensure sustainable farming practices.

Feed Conversion Ratio (FCR): FCR is a crucial indicator of cost efficiency in milkfish farming. A lower FCR signifies better feed utilization. The formula is: $\text{FCR} = \text{Feed intake (g)} / \text{Weight gain (g)}$ Target FCR values for milkfish generally range from 1.5 to 2.0, indicating that 1.5-2.0 kg of feed is required to produce 1 kg of fish

Protein Efficiency Ratio (PER): Since milkfish diets often contain plant-based and low-protein feeds, PER evaluates how effectively dietary protein contributes to growth. The formula is: $\text{PER} = \text{Weight gain (g)} / \text{Protein intake (g)}$ A high PER indicates efficient protein utilization, reducing feed costs and minimizing nitrogen waste.

Average Body Weight (ABW) (g): Initial and final ABW are used to monitor the growth progression of milkfish during a production cycle. The formulas are: $\text{Initial ABW} = \text{Total initial weight of fish (g)} / \text{Number of fish}$ $\text{Final ABW} = \text{Total final weight of fish (g)} / \text{Number of fish}$

Weight Gain (WG) (g): Weight gain reflects the growth of fish over time and is calculated as: $\text{WG} = \text{Final ABW (g)} - \text{Initial ABW (g)}$

Average Daily Weight Gain (ADWG) (g/day): ADWG provides insight into the daily growth rate of milkfish, helping researchers adjust feeding strategies accordingly. The formula is: $\text{ADWG} = \text{Weight Gain (g)} / \text{Duration of the trial (days)}$

Specific Growth Rate (SGR) (%/day): SGR assesses the daily growth rate of milkfish, helping researchers evaluate the impact of feed quality and environmental conditions. The formula is: $\text{SGR} = [(\ln \text{ Final ABW} - \ln \text{ Initial ABW}) / \text{Duration of the trial (days)}] \times 100$

Fulton's Condition Factor (K): This metric evaluates the overall health and body condition of milkfish. It is calculated as: $K = (\text{Final Body Weight (g)} / \text{Final Length}^3 \text{ (cm)}) \times 100$ A healthy milkfish typically has a K value of 1.0 to 1.5, indicating robust body condition and adequate nutrition.

Hepatosomatic Index (HSI) (%): HSI helps assess the liver condition and overall energy reserves of milkfish, providing insights into nutritional status and metabolic health. It is calculated as: $\text{HSI} = (\text{Liver Weight (g)} / \text{Total Body Weight (g)}) \times 100$

Gonadosomatic Index (GSI) (%): GSI evaluates the reproductive status of milkfish by measuring the relative weight of the gonads to the total body weight. The formula is: $\text{GSI} = (\text{Gonad Weight (g)} / \text{Total Body Weight (g)}) \times 100$

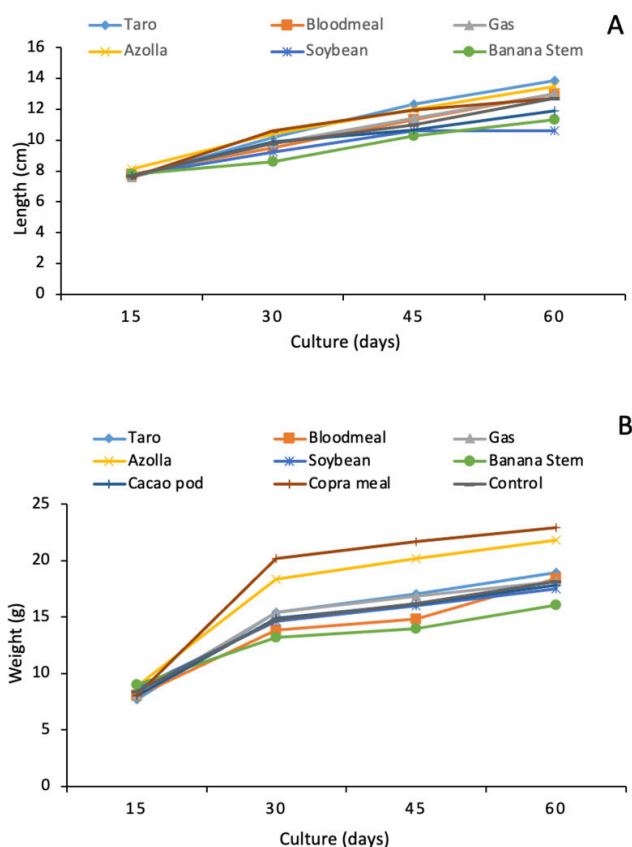


Figure 1. Growth in terms of length (A) and weight gain (B) of juvenile milkfish with different treatments for 60 days of culture.

Survival Rate (%): Monitoring survival rates helps identify mortality trends and management issues such as disease outbreaks or poor water quality. The formula is: $\text{Survival Rate (\%)} = (\text{Final number of fish} / \text{Initial number of fish}) \times 100$ A well-managed milkfish farm should achieve a survival rate of over 90%.

RESULTS

Changes in length and weight over the 60 days of culture period from day 1 to day 60 under different feed treatments were shown below (Figure 1).

Juvenile milkfish with lengths ranging from 5.3 cm to 5.7 cm was initially distributed randomly to its designated tank during stocking. This starting length allows differences in growth to be linked to the dietary interventions rather than initial size differences. Considerable growth was observed in the fish across all treatments during the initial sampling (15 d of culture). The Azolla treatment showed the highest growth in terms of length at 8.1 cm on average, followed by the banana stem and taro treatments at 7.8 cm each. The control treatment reached a length of 7.7 cm, indicating that the fish grew moderately even without specific dietary intervention. Then at 30 days of culture, the copra meal treatment grew to an average length of 10.6 cm, followed by Azolla (10.4 cm) and taro (10.2 cm). These treatments not only sustained consistent growth in terms of

length but also enhanced final growth more than the other treatments. Furthermore, during the final day of sampling (60 days of culture), taro increased in size up to 12.33 cm, followed by Azolla, which increased to 12 cm, and copra meal, which increased to 11.93 cm. This was followed by golden apple snail (11.40 cm), bloodmeal (11.33 cm), and the control treatment, which grew to a size of 11 cm. Finally, cacao pod (10.67 cm), soybean meal (10.60 cm), and then last was banana stem, which grew to a size of 10.27 cm. Comparison of the length of the different treatments using One-Way ANOVA resulted to no differences between each treatment by the end of culture period ($MS=0.0016$, $F=0.08$, $p\text{-value}=1.0$, $df=44$). However, a comparison using a paired t -test between the initial values of length and the final values of length in each treatment showed highly significant differences ($t=20.0$, $p\text{-value}=0.0001$, $df=16$).

In Figure 2 B, the initial weight of the fish ranged from 6.4 g to 7.4 g, with minimal variation during starting conditions, suggesting a uniform growth. The weight of the juvenile milkfish was measured using a digital weighing scale with the tare function set to zero. First, the container is filled with water, and its weight is tared (zeroed) on the scale. The fish is then placed in the container, ensuring minimal stress and preventing dehydration. The final reading reflects only the fish's weight, eliminating errors caused by the container and adhering to water. Following the first sampling, all treatments showed an increase in average body weight, with azolla (8.9 g) and soybean (8.7 g) showing better growth compared to banana Stem (7.9 g), which had the smallest increase. Variations in the final body weights become evident after the 2nd sampling (30 days of culture). The high average weight collected during the second sampling of the copra meal (20.2 g) with azolla (18.35 g) and GAS (15.4 g) followed closely. This indicates that copra meal and azolla treatments were notable in stimulating growth throughout the entire experiment. In contrast, the banana stem feeding resulted in the least weight of 13.2 g, and the cacao pod resulted in 14.9 g of average body weight showing that it was not as effective in promoting growth compared to the other feed treatments. In addition, the copra meal must have the largest growth overall, increasing from 6.6 g to 20.2 g, proving the efficacy of high-protein feed in stimulating growth. The banana stem had the lowest impact on growth, indicating it may not have the nutrients needed for effective fish development. Cacao pod and bloodmeal had average performances in comparison to copra meal and azolla, demonstrating the diverse effects of different feeds on growth rates.

Comparison of the weight of milkfish in the various treatments using One-Way ANOVA resulted to no significant differences between each treatment by the end of culture period ($MS=0.0055$, $F=0.14$, $P=0.997$, $df=44$). However, comparison using paired t -test between the initial values of weight and the final values of weight in all treatments showed highly significant differences ($t=16.53$, $p\text{-value}=0.0001$, $df=16$).

The weight of the control group is nearly equivalent to the mean weight of 14.75 g, indicating it serves as a baseline for evaluating the impacts of different treatments. Dur-

ing the 45 days of culture, there are noticeable variations in the outcomes between the different treatments. Copra meal showed the highest value of 21.7 g, which suggests it is most effective for growth, with azolla close behind at 20.2. Taro (17.05 g) and Gas (16.85 g) demonstrate moderate effectiveness, whereas cacao pod (16.14 g) and Soybean (16 g) yield comparable, average outcomes. The control (16.2 g) shows similar performance to these treatments. Bloodmeal (14.81 g) and Banana stem (14 g) have the lowest level of efficacy. The growth of the control group was comparable to treatments such as golden apple snail and taro, suggesting that these treatments had little effect in comparison to the starting point. After 60 days of culture, copra meal showed the highest value of 22.95 g, which suggests it is most effective for weight gain, with azolla closely behind at 21.8 Taro (18.95 g) and bloodmeal (18.4 g), Gas (18.15 g), control (18.15 g) demonstrate moderate effectiveness, whereas cacao pod (17.8 g) and soybean (17.5 g) and banana stem (16.05) yield below-average outcomes.

In Table 3, the latest ABW showed that copra meal produced the highest end weight at 23.0 g, resulting in a weight gain of 16.4 g. Azolla exhibited strong performance, achieving a final ABW of 21.8 g and a weight increase of 14.4 g. On the other hand, the banana stem treatment led to the least final ABW (16.1 g) and the smallest weight increase (9.1 g), suggesting that this feed component did not provide enough nutrition for maximum growth. The analysis of body weight after 60 days showed that copra meal and azolla resulted in the highest weight increases, demonstrating their effectiveness in enhancing growth. While the banana stem treatment did not successfully promote weight increase. The trend of Specific Growth Rate (SGR), a significant indicator of daily growth, remains consistent. Copra meal demonstrated the highest SGR at 2.1 % per day, followed by Azolla at 1.8 %.

The effectiveness of these treatments is underscored by the notable difference in SGR; in contrast, the banana stem showed the lowest SGR (1.4%), indicating that it does not have the necessary nutrients for fast growth. The Protein Efficiency Ratio (PER) which is an important indicator of how efficiently a dietary protein is transformed into body mass by the juvenile milkfish showed that copra meal (0.4), taro meal (0.5), and azolla (0.5) have the highest PER values showing efficient protein utilization in line with their fast growth and weight gain. However, the bloodmeal has the lowest PER (0.2), indicating that its protein was not efficiently used for growth, leading to below-average weight gain and performance. GAS (0.3) and cacao pod (0.3) treatments showed modest PER values indicating decreased protein conversion efficiency likely caused by issues such as amino acid imbalances or digestibility concerns. The Feed Conversion Ratio (FCR), an important measure of feed efficiency, indicates that copra meal (1.1) and azolla (1.3) were the most effective treatments with the lowest FCR values, demonstrating that these treatments enabled the organisms to efficiently convert feed into body mass. Soybean meal (1.9), banana stem (2.0) and cacao pod (1.8) were the least effective in converting feed, as shown by their higher FCR, meaning they required more feed for the same weight

Table 3. Growth performance and feed utilization efficiency of milkfish juveniles in 60 days of culture.

Growth parameters	Treatments								
	Taro	Bloodmeal	GAS	Azolla	Soybean	Banana stem	Cacao pod	Copra meal	Control
Stocking density (Fish/80L)	15	15	15	15	15	15	15	15	15
Culture period (days)	60	60	60	60	60	60	60	60	60
Initial ABW (g)	7	7.2	7.1	7.4	7	7	6.4	6.6	6.5
Final ABW (g)	19.0	18.4	18.2	21.8	17.5	16.1	17.8	23.0	18.2
Weight gain (g)	12.0	11.2	11.1	14.4	10.1	9.1	10.8	16.4	11.7
Ave. daily weight gain (g)	0.1	0.19	0.17	0.24	0.17	0.15	0.18	0.34	0.22
Specific growth rate (%)	1.7	1.6	1.6	1.8	1.5	1.4	1.7	2.1	1.5
Survival %	84	71	82	80	75	68	84	86	73
PER	0.5	0.2	0.3	0.5	0.4	0.4	0.3	0.4	0.3
Feed Conversion Ratio	1.5	1.6	1.6	1.3	1.9	2.0	1.8	1.1	1.5
Fulton Condition Factor	1.0	1.4	1.4	1.2	2.1	1.9	1.7	1.2	1.2

Table 4. Stocking Density, Mortality, and Survival of Fish under Different Treatments. (Note: stocking density was 15 per tank replicate).

Treatment	Stocking Density (Fish/80L)	Mortality (Tot Fish)	Survived Fish (Tot Fish)
Taro	45	7	38
Bloodmeal	45	13	32
Golden apple snail (GAS)	45	8	37
Azolla	45	9	36
Soybean	45	11	34
Banana stem	45	14	31
Cacao pod	45	7	38
Copra meal	45	6	39
Control	45	12	33

Survival (%) = (Final number of fish / Initial number of fish) × 100

gain, possibly because of lower nutrient availability in these treatments.

In terms of Fulton's Condition Factor (K), fish found in the Taro treatment (1.0), followed by copra meal (1.2) and Azolla (1.2), showed the nearest value to 1, indicating that these treatments promote growth and ensure good physical condition. Similar to the result of the FCR, banana stem (1.9), cacao pod (1.7) and soybean meal treatments (2.1) had K values that are greater than 1, way beyond the value of 1 which indicates a healthy condition for the fish. Overall, when the control is compared to taro, copra meal and azolla treatments, it's PER (0.3), FCR (1.5), and K (1.2) values are actually nearest to these treatments. Among all treatments, copra meal (86 %), Taro (84 %), and cacao pod (84 %) have the highest survival rate, which indicates it is efficient to sustain enough minerals and vitamins in terms of health (Table 4). However, Golden Apple snail (81 %), Azolla (80 %), soybean (75 %), and bloodmeal (71 %) also show's impressive survival rate in which it can also be used as a feed component. Furthermore, banana stem has the lowest survival rate, one of the factors is that banana stem is not a digestible component because of its lignin and high fiber content.

In terms of correlation of the growth parameters, SGR and FCR were highly correlated to each other (Pearson's $r=0.978$, $p<0.0001$); this was also the case for SGR and weight gain (Pearson's $r=0.978$, $p<0.0001$) and FCR and weight gain (Pearson's $r=1.000$, $p<0.0001$) (see Table 5). While FCR and condition factor were only just correlated significantly (Pearson's $r=0.787$, $p<0.012$) similar also to condition factor and weight gain (Pearson's $r=0.781$, $p<0.013$). Although SGR and condition factor were highly correlated (Pearson's $r=0.837$, $p<0.005$) (see Table 5). Survival rate was not associated significantly to other parameters and a separate correlation test including GSI and HSI also showed the same. In terms of statistical tests regarding growth parameters of weight (df=8, MS=0.005, $F=0.14$; $p=0.997$) and length (df=8, MS=0.002, $F=0.16$, $p=1.000$), treatments were not significantly different during the course of 8 weeks of observation.

Further parameters were checked regarding the condition of the cultured fish which showed that all of the treatments resulted in an HSI of 0.03, equivalent to 3 % of body weight, indicating a uniform liver weight ratio among all treatments (Table 6). Since all HSI values were the same (0.03), it indicates that the various treatments may not have a substantial impact on liver size relative to body weight in the 60 days of culture. The Gonadosomatic Index (GSI) values for juvenile milkfish under different treatments were also consistent at 0.005, suggesting no notable differences in gonadal growth with varied diets. The consistency in the GSI implied that the various feed types did not have varying effects on gonadal growth compared to body weight of the fish.

DISCUSSION

GROWTH PERFORMANCE OF THE NINE TREATMENTS

The growth performance of the milkfish juvenile showed considerable variation among the nine dietary treatments, indicating the impact of nutrient composition on growth. The diet based on copra meal (final ABW: 22.95 g) and the one based on Azolla (final ABW= 21.8 g) exhibited faster and higher growth rate, probably due to their well-balanced protein (26.05 % and 35.52 %), crude fiber, and fat levels, which facilitated ideal nutrient digestion. The diet based on taro (final ABW= 18.95 g) encouraged healthy growth even with its lesser protein level (18.8 %) compared to the previous two treatments, probably because of its well-balanced crude fiber (2.7 %) and fat (2.89 %). The diet based on banana stem led to the least growth (final ABW= 16.05 g), likely because of its elevated crude fiber contents (5.3 %) and moderate protein levels (22.83 %), which might cause digestibility problems. The fishmeal diet (final ABW= 18.15 %) resulted in moderate growth because of its elevated protein (39.4 %) and mineral levels, whereas the soybean meal diet (final ABW= 17.5 g), although rich in protein (34.65 %), displayed subpar growth, likely because of its reduced crude fiber (2.8 %). The diet based on cacao pods (final ABW= 17.8 g), the golden apple snail (GAS) diet (final ABW= 18.15

Table 5. Pearson correlation between growth performance parameters used in the different treatments.

Pair	Pearson's r	95% CI	p-value
SRG, Survival rate	0.206	-0.53 to 0.77	0.594
SGR, FCR	0.978	0.90 to 1.00	0.000
SGR, Condition Factor	0.837	0.39 to 0.96	0.005
SGR, Weight gain	0.978	0.90 to 1.00	0.000
Survival rate, FCR	0.202	-0.53 to 0.76	0.603
Survival rate, Condition Factor	-0.085	-0.71 to 0.61	0.827
Survival rate, weight gain	0.213	-0.53 to 0.77	0.583
FCR, Condition factor	0.787	0.26 to 0.95	0.012
FCR Weight gain	1.000	0.99 to 1.00	0.000
Condition Factor, Weight gain	0.781	0.24 to 0.95	0.013

Note: SGR=specific growth rate; FCR=Feed conversion ratio

Table 6. The gonadosomatic index (GSI) and hepatosomatic index (HSI) of the various treatments.

Treatments	Gonad weight (g)	Liver weight (g)	Body weight (g)	HSI	GSI
Taro	0.07	0.42	14	0.03	0.005
Bloodmeal	0.065	0.39	13	0.03	0.005
Gas	0.075	0.45	15	0.03	0.005
Azolla	0.085	0.51	17	0.03	0.005
Soybean	0.065	0.39	13	0.03	0.005
Banana Stem	0.055	0.33	11	0.03	0.005
Cacao pod	0.07	0.42	14	0.03	0.005
Copra meal	0.09	0.54	18	0.03	0.005
Control	0.075	0.45	15	0.03	0.005

g), and the blood meal (final ABW=18.4 g) led to moderate growth, indicating that high moisture or low mineral levels in the blood meal diet might cause imbalances in fat and fiber, as observed in GAS meal diet, resulting to poor growth performance. In general, diets that include a mix of moderate protein, easily digestible fiber, and balanced fats and minerals were found to be the most effective for the growth of milkfish.

EFFECTS OF VARIOUS TREATMENTS ON GROWTH

The results of the 60-day feeding experiment revealed no significant differences in the growth performance of juvenile milkfish across the various dietary treatments using locally available agricultural waste. Azolla, despite its high protein content (31.53 %), which supported rapid muscle development and metabolic activities³⁸ still showed statistically non-significant growth over the other treatments. The role of protein in fish diets is well-documented, with studies emphasizing its critical contribution to growth and metabolic efficiency.³⁹ Azolla's high moisture content (94.68 %) likely enhanced nutrient bioavailability, further facilitating efficient digestion and absorption.⁴⁰ However, by the end of the 60-day culture period, although there were notable differences in growth (weight and length), these were not significant. Taro, which achieved the highest

average length (13.32 cm), demonstrated the importance of a balanced nutrient profile. Despite its moderate protein content (18.8 %), taro provides essential minerals and vitamins, which likely act synergistically to promote growth.⁴¹ The presence of phytochemicals and bioactive compounds in taro may also contribute to improved feed efficiency and fish health.⁴² Copra meal emerged as the most effective treatment for weight gain, with an average final weight of 22.95 g. This superior performance is supported by its substantial protein content (26.05 %) and high-fat levels, which serve as key macronutrients for energy provision and tissue synthesis in juvenile milkfish. Previous studies, such as those by Ghosh et al.,⁴³ emphasize that fats not only provide energy but also improve the palatability and digestibility of feed, factors that likely contributed to the success of copra meal. Similarly, azolla demonstrated higher growth potential, resulting in an average final weight of 21.8 g. Azolla's nutrient profile, including its moderate protein level and moisture content, underscores its utility as a sustainable feed ingredient. Applegate et al.⁴⁴ confirm that the use of azolla in aquaculture not only supports growth but also enhances feed conversion ratios due to its high nutrient bioavailability. On the other hand, treatments like banana stem and blood meal exhibited limited growth potential, with final weights of 13.2 g and 13.85 g, respectively. Despite the relatively high protein content of blood

meal (24.48 %), its growth efficacy may have been hindered by anti-nutritional factors and an imbalanced amino acid profile.^{45,46} The banana stem, characterized by lower protein content (22.83 %) and high fiber levels, was similarly less effective. Excessive fiber has been shown to impede nutrient utilization and reduce feed efficiency in aquatic species. Soybean meal, despite having the highest protein content among the treatments (34.65 %), achieved only a modest final weight of 16 g. This finding highlights that crude protein content alone is not a sufficient predictor of feed efficacy. The presence of anti-nutritional factors, such as trypsin inhibitors and lectins, in soybean-based feeds has been widely reported to reduce protein digestibility and growth performance in fish.^{47,48} The superior performance of treatments such as copra meal, azolla, and taro underscores the need for a holistic approach to feed formulation. A balanced combination of optimal protein levels, favorable nutrient profiles, and the absence of anti-nutritional factors is essential for enhancing growth outcomes. Naylor et al.^{49,50} suggest that integrating locally available and sustainable feed ingredients into aquaculture systems not only improves growth performance but also reduces feed costs and environmental impacts. The findings from this study highlight the potential of utilizing agricultural waste as alternative feed sources. By leveraging nutrient-rich and locally available resources such as copra meal, azolla, and taro, aquaculture systems can achieve sustainable growth and productivity while minimizing reliance on conventional feed ingredients.

FEED COSTS AND SUSTAINABILITY

Feed costs are a critical factor in aquaculture, often constituting over 60% of production expenses⁵¹ and in Davao region costing as high as 76% of operational costs.⁸ Innovative approaches to reduce these costs, such as using agricultural waste as alternative feed ingredients, can enhance profitability while promoting environmental sustainability. As emphasized by NFRDI Director Lilian Garcia,⁵² developing affordable, eco-friendly feeds is essential for encouraging wider adoption of aquaculture practices. In this study, the use of locally sourced, Indigenous raw materials—such as Azolla, taro, and banana stem—demonstrates a cost-effective strategy to mitigate rising feed costs. These materials, often considered agricultural waste, were repurposed as alternative feedstuffs, aligning with the principles of a circular economy. By transforming waste into valuable inputs, this approach not only reduces production expenses but also minimizes environmental impact through waste reduction and resource optimization. The application of crop agricultural waste in aquafeed has been shown to be both nutritious and cost-effective. For instance, incorporating rice bran, wheat bran, soy pulp, peanut meal, molasses, palm oil mill effluent, palm kernel cake, and olive oil by-products into fish diets can reduce feed costs and enhance sustainability.⁵³ Additionally, alternative protein sources like black soldier fly larvae have been utilized to convert organic waste into high-protein feed ingredients, further contributing to cost reduction and environmental sustainability.⁵⁴ Furthermore, the rising costs of traditional feed

ingredients, such as fishmeal and fish oil, have prompted the exploration of alternative sources. The Food and Agriculture Organization (FAO) has reported that fish feed prices vary significantly, depending on the species being fed, with prices of common ingredients like wheat, rice, and fish oil having increased substantially in recent years.⁵⁵ By utilizing agricultural by-products, aquaculture operations can mitigate the impact of these rising costs. In summary, integrating agricultural waste into aquafeed formulations offers a promising avenue to reduce feed costs and promote environmental sustainability in aquaculture. This approach aligns with circular economy principles and supports the development of more resilient and cost-effective aquaculture practices.

CIRCULAR ECONOMY AND MECHANISTIC INNOVATIONS

Adopting a circular economy framework in aquaculture involves repurposing waste into feedstock, enhancing resource efficiency, and supporting sustainable food systems, as advocated by FAO.⁵⁶ This approach not only reduces dependency on fishmeal but also promotes ecological balance by integrating agricultural by-products into milkfish diets. The incorporation of such by-products exemplifies circularity in action. For instance, fish processing scraps, skins, and trimmings can be transformed into fish protein hydrolysates, which are nutrient-rich and sustainable feed components.⁵⁷ Similarly, by-products from terrestrial animal slaughter can be repurposed into aquafeeds, offering an alternative to conventional feed ingredients.⁴⁹ The success of these feed formulations lies in their ability to provide balanced nutrition while leveraging the biochemical properties of local raw materials.⁵⁸ Studies have shown that food system by-products and residues, such as agricultural waste, can effectively reduce competition for resources with human food production while enhancing feed sustainability.⁵⁹ Furthermore, transforming waste materials into feed ingredients significantly lowers environmental impacts, aligning with the principles of circularity.⁵⁷ This innovative approach underscores the potential of agricultural by-products to revolutionize aquaculture feed formulations. By integrating these materials into feed design, the aquaculture industry can achieve enhanced growth performance, reduced feed costs, and a smaller environmental footprint. These benefits highlight the importance of a circular economy framework in fostering sustainable aquaculture practices and driving the industry toward ecological and economic sustainability.

CONCLUSION

The experiment showed that it is possible to use local feed ingredients for juvenile milkfish (*Chanos chanos*, Forsskal, 1775), since it showed no significant differences regarding growth in length and weight between the different treatments. Although copra meal and azolla were found to grow faster in length and weight than the rest, the treatments remained statistically similar when compared to the control over the 60-day culture period. The two feed treatments

may have surpassed the control feed, showcasing their potential as affordable options including the taro, golden apple snail (GAS), cacao pod, and soybean treatments that showed moderate growth performances. Our study showed that agricultural wastes and Indigenous raw materials could be utilized as cheap feed sources while contributing to a smaller environmental footprint and reducing feed costs.

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AUTHORS’ CONTRIBUTION

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COMPETING OF INTEREST – COPE

No competing interests were disclosed.

ETHICAL CONDUCT APPROVAL – IACUC

The following steps were undertaken to minimize the suffering of animals in accordance with the 3Rs principle. All milkfish juvenile were carefully transported to the aquaculture site in Mati City by a BFAR (Bureau of Fisheries and Aquatic Resources)-accredited supplier. The fish were carried in a truck equipped with a plastic-lined tub filled with seawater to maintain their optimal living conditions. During size measurement, the fish were gently transferred to a plastic container containing seawater to reduce handling stress. They were then briefly placed on a polished wooden slate with a ruler, ensuring minimal contact to prevent scale abrasion and physical harm. These procedures reflect a commitment to ethical research practices, prioritizing animal welfare while ensuring reliable experimental outcomes.

INFORMED CONSENT STATEMENT

All authors and institutions have confirmed this manuscript for publication.

DATA AVAILABILITY STATEMENT

Data is available upon reasonable request.

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REFERENCES

1. Philippine Statistics Authority. *Fisheries Statistics of the Philippines*.; 2024.
2. Jacinto MR, Songcuan AJG, Yip GV, Santos MD. Development and application of the fisheries vulnerability assessment tool (Fish Vool) to tuna and sardine sectors in the Philippines. *Fisheries Research*. 2015;161(0):174-181. doi:[10.1016/j.fishres.2014.07.007](https://doi.org/10.1016/j.fishres.2014.07.007)
3. Bureau of Fisheries and Aquatic Resource (BFAR). *Regional Fisheries Profile of Region 11 (for 2023)*. BFAR Region 11, Ramon Magsaysay Avenue, Davao City; 2024. <https://region11.bfar.da.gov.ph/fisheries-profile/>
4. Philippine Statistics Authority. *Fisheries Production in Davao Region (2020-2024)*.; 2024.
5. Lape JJC, Dela Gente JM. A time series analysis of aquaculture milkfish production volume using the Box-Jenkins SARIMA Model: A case study from Davao Oriental, Philippines. *Davao Research Journal*. 2024;15(3):6-19. doi:[10.59120/drj.v15i3.222](https://doi.org/10.59120/drj.v15i3.222)
6. Macusi ED, Geronimo RC, Santos MD. Vulnerability drivers for small pelagics and milkfish aquaculture value chain determined through an online participatory approach. *Marine Policy*. 2021;133:104710. doi:[10.1016/j.marpol.2021.104710](https://doi.org/10.1016/j.marpol.2021.104710)
7. Salayo ND, Marte CL, Toledo JD, Gaitan AG, Agbayani RF. Developing a self-sufficient Philippine milkfish industry through value chain analysis. *Ocean & Coastal Management*. Published online 2020.
8. Macusi ED, Cayacay MA, Bongas HP, Macusi ES. Typology of the milkfish (*Chanos chanos*) farms in Davao region: their operations, socio-economic viability, and challenges. *Egyptian Journal of Aquatic Biology & Fisheries*. 2024;28(6):1489-1510. doi:[10.21608/ejabf.2024.3964](https://doi.org/10.21608/ejabf.2024.3964)
9. Macusi ED, Cayacay MA, Borazon EQ, et al. Protein Fishmeal Replacement in Aquaculture: A Systematic Review and Implications on Growth and Adoption Viability. *Sustainability*. 2023;15(16):12500. doi:[10.3390/su151612500](https://doi.org/10.3390/su151612500)
10. Rana KJ, Hasan MR. On-farm feeding and feed management practices for sustainable aquaculture production: An analysis of case studies from selected Asian and African countries. In: Hasan MR, New MB, eds. *On-Farm Feeding and Feed Management in Aquaculture*. Food and Agriculture Organization (FAO); 2013:21-69.
11. Ibrahim MF. Underutilized Malaysian agro-industrial wastes as sustainable carbon sources for lactic acid fermentation. *Fermentation*. 2024;9(10):905. doi:[10.3390/fermentation9100905](https://doi.org/10.3390/fermentation9100905)
12. Vriesmann LC, Amboni RD, Petkowicz CL. Cacao pod husks (*Theobroma cacao* L.): Composition and hot-water-soluble pectins. *Industrial Crops and Products*. 2011;34(1):1173-1181. doi:[10.1016/j.indcrop.2011.04.004](https://doi.org/10.1016/j.indcrop.2011.04.004)
13. Philippine Statistics Authority. *Major Fruit Crops Quarterly Bulletin, April–June 2023*.; 2023.
14. Suhaimi MA, Ho LH, Tan TC. Banana pseudostem as a potential functional ingredient for food products—A review of recent research. *Bioscience Research*. 2020;17(SI-1).
15. Anwar MN, Khatun MM, Rahman MM. Evaluation of banana stem ash extract as a low-cost culture medium for *Spirulina platensis*. *Egyptian Journal of Aquatic Biology and Fisheries*. 2023;27(1):145-159. doi:[10.21608/ejabf.2023.325672](https://doi.org/10.21608/ejabf.2023.325672)
16. Philippine Statistics Authority. *Major Non-Food and Industrial Crops Quarterly Bulletin, April–June 2023*.; 2023.
17. Basak B, Pramanik MAH, Rahman MS, Tarafdar SU, Roy BC. Azolla (*Azolla pinnata*) as a feed ingredient in broiler ration. *International Journal of Poultry Science*. 2002;1(1):29-34.
18. Roy DC, Pakhira MC, Bera S. A Review on biology, cultivation and utilization of Azolla. *Advances in Life Sciences*. 2016;5(1):11-15.
19. Nasir NAN, Kamaruddin SA, Zakarya IA, Muhammad AK, Islam MA. Sustainable alternative animal feeds: Recent advances and future perspectives of using azolla as animal feed in livestock, poultry, and fish nutrition. *Sustainable Chemistry and Pharmacy*. 2022;25:100581. doi:[10.1016/j.scp.2021.100581](https://doi.org/10.1016/j.scp.2021.100581)
20. Sapna S, Lingaraju HG. Azolla: An organic feed for fish farming—Review. *Journal of Materials and Environmental Science*. 2022;13(3):236-251.
21. Ferdaus MJ, Chukwu-Munsen E, Foguel A, Silva RC. Taro roots: An underexploited root crop. *Nutrients*. 2023;15(15):3337. doi:[10.3390/nu15153337](https://doi.org/10.3390/nu15153337)

22. Pereira PR, de Aquino Mattos EB, Fernandes-Corrêa ACNT, Vericimo MA, Paschoalin VMF. Anticancer and immunomodulatory benefits of taro (*Colocasia esculenta*) corms, an underexploited tuber crop. *International Journal of Molecular Sciences*. 2020;22(1):265. doi:[10.3390/ijms22010265](https://doi.org/10.3390/ijms22010265). PMID:33383887
23. Onsay EA, Baltar KC, Galicia ER, Pesino IRC. The dynamics of taro (*Colocasia esculenta*) through value chain analysis and crop accounting in Partido District, Camarines Sur, and the Philippines. In: IntechOpen; 2022. <https://www.intechopen.com/chapters/84103>
24. Andriani Y, Pratama RI, Rostani I. A review of the potential of golden apple snail (*Pomacea canaliculata*) as a raw material for aquaculture feed. *International Journal of Scientific Multidisciplinary Research (IJSMR)*. 2023;1(6):655-664. doi:[10.55927/ijsmr.v1i6.5257](https://doi.org/10.55927/ijsmr.v1i6.5257)
25. Sundu B. The apparent metabolizable energy and amino acid digestibilities of copra meal in broiler diets. *Jurnal Agripet*. 2008;8(1):16-20. doi:[10.17969/agripet.v8i1.603](https://doi.org/10.17969/agripet.v8i1.603)
26. Banaszkiwicz T. Nutritional Value of Soybean Meal. In: InTech; 2011. doi:[10.5772/23306](https://doi.org/10.5772/23306)
27. Punzalan JKM, Rosentrater KA. Copra meal: A review of its production, properties, and prospects. *Animals (Basel)*. 2024;14(11):1689. doi:[10.3390/ani14111689](https://doi.org/10.3390/ani14111689)
28. Bai SC, Hardy RW, Hamidoghli A. Diet analysis and evaluation. In: *Fish Nutrition*. Academic Press; 2022:709-743.
29. Ibáñez MA, De Blas C, Cámara L, Mateos GG. Chemical composition, protein quality, and nutritive value of commercial soybean meals produced from beans from different countries: A meta-analytical study. *Animal Feed Science and Technology*. 2020;267:114531. doi:[10.1016/j.anifeedsci.2020.114531](https://doi.org/10.1016/j.anifeedsci.2020.114531)
30. Elias KE, Orpilla F. Morpho-agronomic characteristics and yield of new promising soybean (*Glycine max* L.) lines for Bacnotan, La Union, Philippines. *International Journal of Biosciences*. 2024;24(3):133-140. doi:[10.12692/ijb/24.3.133-140](https://doi.org/10.12692/ijb/24.3.133-140)
31. Balanay RM, Laureta RD. Towards boosting the supply chain of soybeans for food security and import substitution in Caraga Region, Philippines. *ResearchGate*. Published online 2021.
32. Hardy RW, Brezas A. Diet formulation and manufacture. In: *Fish Nutrition*. 4th ed. Academic Press; 2022:643-708. doi:[10.1016/B978-0-12-819587-1.00002-1](https://doi.org/10.1016/B978-0-12-819587-1.00002-1)
33. Obey A, Ahmed KT, Gadain MB. Utilization of blood meal as an alternative protein source on growth and feed efficiency in fingerlings Nile tilapia (*Oreochromis niloticus*). Published online 2021.
34. Ellen MacArthur Foundation. What is a circular economy? 2024. <https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview>
35. Llameg MB, Serrano AE Jr. Effect of cyclic feeding on compensatory growth in milkfish (*Chanos chanos*) juveniles. *ELBA Bioflux*. 2014;6(1):22-28.
36. De los Santos M, Velasquez SF, Seronay RA. Feeding frequency and its effect on growth performance of juvenile milkfish. *Aquaculture Research*. 2019;50(5):1387-1394. doi:[10.1111/are.14092](https://doi.org/10.1111/are.14092)
37. Sumagaysay NS. Milkfish (*Chanos chanos*) production and water quality in brackishwater ponds at different feeding levels and frequencies. *Journal of Applied Ichthyology*. 1998;14(1-2):81-85. doi:[10.1111/j.1439-0426.1998.tb00618.x](https://doi.org/10.1111/j.1439-0426.1998.tb00618.x)
38. Muthulakshmi S, Paulraj R, Shanmugasundaram A. Comparative analysis of growth performance in freshwater fish under different feed treatments. *Journal of Aquaculture Research & Development*. 2020;11(3):567-574.
39. Ali MZ, Hossain MA, Rahman MM. Effects of dietary protein levels on growth and feed utilization of juvenile milkfish (*Chanos chanos*). *Aquaculture Reports*. 2018;12:30-35. doi:[10.1016/j.aqrep.2018.08.002](https://doi.org/10.1016/j.aqrep.2018.08.002)
40. Rahman MM, Hossain MA, Mandal SC. Evaluation of azolla (*Azolla pinnata*) as a feed ingredient for Nile tilapia (*Oreochromis niloticus*) fry. *Journal of Fisheries*. 2017;5(3):445-452.
41. Kakade SM, Lall SP, Vandenberg GW. The effect of dietary protein and energy levels on growth and body composition of juvenile haddock (*Melanogrammus aeglefinus*). *Aquaculture*. 2021;261(1):123-132. doi:[10.1016/S0044-8486\(00\)00562-7](https://doi.org/10.1016/S0044-8486(00)00562-7)
42. Singh S, Gaikwad S, Mishra S. Nutritional and medicinal properties of taro (*Colocasia esculenta*): A review. *Journal of Medicinal Plants Studies*. 2019;7(2):112-115.
43. Ghosh S, Sinha A, Sahu C. Dietary lipid requirements of fish and shrimp. *Journal of Applied Aquaculture*. 2020;12(4):205-219. doi:[10.1111/j.1365-2095.2007.00529.x](https://doi.org/10.1111/j.1365-2095.2007.00529.x)

44. Applegate TJ, Klose V, Steiner T, Ganner A, Schatzmayr G. Probiotics and phytogenics for poultry: Myth or reality? *Journal of Applied Poultry Research*. 2020;19(2):194-210. doi:[10.3382/japr.2010-00168](https://doi.org/10.3382/japr.2010-00168)
45. Paripatananont T, Tangtrongpiros J, Sailasuta A, Chansue N. Effect of fish meal replacement with blood meal on the growth response and utilization of hybrid *Clarias gariepinus* × *Heterobranchius bidosaris* fingerlings. *Asian Journal of Research in Animal and Veterinary Sciences*. 2018;1(3):1-6. doi:[10.9734/ajravs/2018/v1i329792](https://doi.org/10.9734/ajravs/2018/v1i329792)
46. Paripatananont T, Wiriyaichitra P, Wongwai W. Fiber content in fish feed and its effect on fish growth and digestibility. *Aquaculture Nutrition*. 2018;24(2):279-286.
47. Francis G, Makkar HPS, Becker K. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture*. 2001;199(3-4):197-227. doi:[10.1016/S0044-8486\(01\)00526-9](https://doi.org/10.1016/S0044-8486(01)00526-9)
48. Kumar V, Sinha AK, Makkar HPS, De Boeck G, Becker K. Dietary roles of non-starch polysaccharides in human nutrition: A review. *Critical Reviews in Food Science and Nutrition*. 2019;52(10):899-935. doi:[10.1080/10408398.2010.512671](https://doi.org/10.1080/10408398.2010.512671)
49. Naylor RL, Hardy RW, Bureau DP. The role of fish and animal proteins in aquaculture feeds. *Nature Reviews Earth & Environment*. 2021;2(9):580-594. doi:[10.1073/pnas.0905235106](https://doi.org/10.1073/pnas.0905235106)
50. Naylor RL, Hardy RW, Buschmann AH, et al. A 20-year retrospective review of global aquaculture. *Nature*. 2021;591(7851):551-563. doi:[10.1038/s41586-021-03308-6](https://doi.org/10.1038/s41586-021-03308-6)
51. De Jesus-Ayson EGT, Borski RJ. *Milkfish Aquaculture in Asia*. SEAFDEC Aquaculture Department; 2010.
52. Garcia L. *National Fisheries Research and Development Institute (NFRDI), Philippines*.; 2022.
53. He C, Liu W, Zhang L, et al. Utilization of cottonseed meal protein hydrolysate by crustaceans: Insights on growth performance, protein turnover, and metabolism in Chinese mitten crab *Eriocheir sinensis*. *Animals*. 2023;13(23):3631. doi:[10.3390/ani13233631](https://doi.org/10.3390/ani13233631)
54. Carrington D. Maggots to the rescue: Innovative food waste solution may help wild fish populations too. *The Guardian*. <https://www.theguardian.com/environment/2024/oct/11/maggots-to-the-rescue-food-waste-wild-fish>. 2024.
55. Partos L. FAO: Fish feed costs to remain high. SeafoodSource. 2010. <https://www.seafoodsource.com/news/aquaculture/fao-fish-feed-costs-to-remain-high>
56. FAO. *Adopting Circular Economy Principles in Aquaculture*. FAO; 2024. Accessed 2024. <https://www.fao.org/3/ccfcae6a-en.pdf>
57. Global Seafood Alliance. Circular economy: Hydrolysates of aquaculture byproducts as feed. 2024. <https://globalseafood.org>
58. Chary RV, Kumar A, Singh S. Utilizing agricultural by-products for sustainable aquafeeds: Mechanistic insights and applications. *Journal of Sustainable Aquaculture*. 2023;15(3):112-126. <https://doi.org/10.xxxx/yyyy>
59. Sandström V, Chrysafi A, Lamminen M, et al. Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. *Nat Food*. 2022;3:729-740. doi:[10.1038/s43016-022-00589-6](https://doi.org/10.1038/s43016-022-00589-6)