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Non-Fishmeal Based, and Selected Indigenous Raw Materials as Cost-Effective Feeds for Milkfish Aquaculture

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Abstract: This study aimed to find alternative feeds or supplementary feeds that can perform similarly to the existing commercial feeds thereby reducing farmer expense and cutting down their cost of production and increasing their profitability. The formulations for the study included four grow-out treatments mainly: control (commercial feed), taro+control (powdered *Colocasia esculenta*+commercial fish feed), bloodmeal (formulated fish feed based on bloodmeal), banana stem+control (chopped banana stem+commercial fish feed). A total of 12,000 fingerlings initially weighing 16 g (TL=10 cm) individually were assigned randomly to the four treatments (3000 in each cage measuring 6 x 6 m). The result of the study showed no significant differences between feed treatments from 6th week onwards, whether with weight [MS=0.130, df=3, F=1.14, P=0.333] or total length of the treatments [MS=0.008, df=3, F=0.40, P=0.75]. The FCR ratio showed bloodmeal (1.60) as lowest, followed by the control (1.65), and taro+commercial (1.71) and then banana stem+commercial (2.18). In terms of weight gain, fish from the bloodmeal treatment gained the highest (236.97 g), followed by control (223.33 g), then taro (217.67 g) and banana stem (196.99 g). As a result, we find that any of the tested treatments can serve as an alternative feed to using purely commercial fish feeds. Cost-benefit analysis showed that a better gross profit margin of 42% and cost-benefit ratio of 1.37 was observed in taro+commercial feed diet.

Keywords: banana stem; bloodmeal; circular economy; milkfish (*Chanos chanos*); taro (*Colocasia esculenta*)

Introduction

Aquaculture in the Philippines has a long history, the earliest type of aquaculture in the Philippines was milkfish farming, which started in the Philippines approximately 400–600 years ago and then expanded to Indonesia, Taiwan, and other parts of the Pacific (Bagarinao, 1999; FAO, 2009). It is essential for the food security and economic stability of fish farmers in the Philippines, with fisherfolk numbering close to 1.6 million fishers and fish farmers (Macusi et al., 2020; Macusi et al., 2022). The Philippines is ranked 11th as the world's top producer of fisheries, and the Philippines' fisheries rely heavily on aquaculture, with coastal aquaculture being the dominant form of production (Guerrero, 2019). In recent years, there is a clamor of fish farmers for a cheaper feed alternative to current feed. Various fish feed formulations similar to poultry and other livestock in the market are pernicious for their high costs. The favorability of fishmeal as a feed ingredient and its increasing scarcity have driven up its price (up to USD 1210/t) (Rana et al., 2009). This is partly responsible for the high costs of fish feed (Lukuyu et al., 2014). It has been reported that in Africa, fish feed accounts for about 60% of the total cost of fish production (Lawal et al., 2012), while in the Philippines this is reported to be as high as 80% of the cost of fish farming operation (Macusi et al.,

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2023b). The high costs of fishfeeds limits the ability of fish farmers to intensify their aquaculture production (Aya, 2017). Alternative feeds or supplementary feeds that can perform similarly to the existing commercial feeds may reduce the expenses of farmers, cutting down their cost of production to increase profitability.

Some examples of agricultural crops that have potential for feed use includes taro (*Colocasia esculenta*), cassava (*Manihot esculenta*), coprameal, ipil-ipil (*Leucaena leucocephala*), banana (*Musa balbisiana/acuminata* hybrid), cacao pods (*Theobroma cacao*), and other agricultural waste products. Taro is known to be an alternative food, high in starch, protein and vitamins and minerals which is considered native to Southern India, Southeast Asia and has good distribution in Africa, Polynesia, South America, and Japan (Onsay et al., 2022). Taro leaves are popularly used for food dishes such as *laing* and *pinangat* in Bicol region. It is considered as a backyard plant and giving taro harvests for animal feed is a common practice in the rural areas in the Philippines utilizing its leaves, petioles and peelings normally chopped, cooked and fed directly to hogs (Matthews, 2012). Other processed products of taro are taro flour, cookies, noodles, achu and it is also a major constituent of baby food products due to its easily digestible nature (Aditika et al., 2021). Archeological surveys in the Solomon Islands suggest that taro was one of the oldest domesticated crops and used as far back as 28,000 years ago (Lebot, 2020; Loy et al., 1992).

Moreover, the Philippines, like many agricultural countries face problems of waste disposal (Abreo et al., 2020; Macusi et al., 2019), especially for agricultural waste products including banana stem, leaves, rejected fruits, coconut husks, and shell and coffee bean wastes (Dou et al., 2018). Previously, it has been stated that green banana wastes and coffee pulp are promising waste products that can be utilized as animal feeds (Ulloa et al., 2004). Banana production in the Philippines reached 9 million tons in 2020 of which Mindanao region ranks first in production, 52% of which was Cavendish for export (Gueco, 2022). Worldwide, about 114.08 million metric tons of banana waste-loss are produced, leading to environmental problems which could be turned to cellulose, hemicellulose and natural fibers and modified to obtain bioplastics, organic fertilizers and biofuels or animal feeds (Alzate Acevedo et al., 2021). In Africa, specifically Nigeria which is known to have large banana production, fish culture is gaining importance and seeking to develop locally available raw materials such as yam (*Dioscorea esculenta*), banana (*Musa paradisiaca*), cowpeas (*Vigna unguiculata*), mucuna (*Mucuna acuminata*), maize (*Zea maize*), cassava (*Manihot esculenta*), millet (*Panicum miliaceum*), sorghum (*Sorghum bicolor*), groundnut (*Arachis hypogaea*), sunhemp (*Crotalaria juncea*) seed and brewery wastes for fish feed (Audu and Yola, 2020). Other non-conventional feeds have been recommended for extensive culturing for Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) to save on costs such as leaves of gallant soldier (*Galisonga parviflora*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and papaya (*Papaya carica*) which were identified as high potential feedstuffs of plant origin either processed or in raw form for small-scale fish farming (Munguti et al., 2012).

Moreover, there are efforts to recycle and use agricultural wastes but are not widely adopted in the agro-industrial sectors for various reasons such as lack of assessment, adoption and intermittent supply which dampen farmer's enthusiasm to use the product (Sun et al., 2024). An encouraging sign is the current drive to use food loss and agricultural wastes and turn them to animal feeds since these contain high crude protein especially plant seeds, shells, fruit pulp, and mushroom substrate (Quintero-Herrera et al., 2023; Siddique et al., 2024). The use of agricultural wastes, including fruit wastes is being adopted for a sustainable circular economy model for human production and consumption (Medhekar, 2024). This is the key to reducing waste, environmental impact and securing a sustainable future for farmers, businesses, and the household sectors (Gatto et al., 2024). Thus, being able to find a cheaper feed alternatives from these agricultural wastes mean a lot in terms of valorization of wastes, sustainable development, and as a contribution to promoting the circular economy (Dou et al., 2024). A circular economy offers a model for improving resource efficiency by regenerating ecosystems, maintaining resources, eliminating waste, and enhancing business models (Hoof et al., 2024).

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Cheaper alternative feeds can help increase the profit of fish farmers. Despite the high growth rate of aquaculture in the Philippines, e.g. producing 415,000 metric tons of milkfish in 2019, feed cost hampers plans for expansion of production. Davao region's milkfish production started to increase from 19,000 mt in 2019 to 20,000 mt in 2021, showing an increasing trend of production (PSA, 2022). Likewise, the milkfish aquaculture production in Davao Oriental from 2015 to 2023 reached a total production of 7,594.23 mt. Additionally, the total milkfish production in 2023 was only 240.23 mt, about 53.96% and 81.28% decrease compared to the last output in 2022 and 2021, which were, 521.84 and 1,283.18 mt (PSA, 2024). Cultured species range from freshwater species like tilapia, catfish, and mud crab to brackishwater species such as milkfish and white shrimp. Mariculture, or aquaculture at sea using fish cages or pens, is primarily practiced at the Mati Mariculture Park in barangay Badas, Mati, which has 29 cage modules dedicated to milkfish production where this study was conducted from May to August this year.

This study aimed to find locally available indigenous feed materials and develop feed formula/s using such raw materials to assist the milkfish aquaculture industry towards inclusion and sustainability. Moreover, this will assess locally developed feed materials for the growth response of juvenile milkfish in grow-out culture and determine their cost-benefit ratio to commercially available feeds.

Materials and Methods

Description of Treatments

For the milkfish grow-out treatments, selected fish feeds based on the most promising suggestion from an earlier result of our previous study (Macusi et al., 2023c) and the literature (Alzate Acevedo et al., 2021; Ulloa et al., 2004) were used for this experiment and compared to the commercial feeds. For instance, we used taro, bloodmeal and banana stem which are considered as tubers, root crops, slaughterhouse and agricultural wastes. The experimental cages were divided into commercial (control), taro and commercial (50% by weight combination), banana stem (green, shredded)+commercial (50% by weight combination), bloodmeal-based feed. The juvenile milkfish were fed three to four times a day based on farmer's practice in the area (08hr, 10hr, 12hr and 16hr) and observed for 12 weeks (84 days) during the grow-out phase. Their growth performance was then compared to the commercial treatment in terms of weight and size in a grow-out setting. The grow out cages are composed of a floating fish cage with four modular fish cages measuring 6 x 6 m stocked with 3000 juvenile milkfish for a total of 12,000 juvenile milkfish. The initial weight of stocked juvenile milkfish in the four treatments were 18 g, 19.2 g, 17 g and 19.6 g (n=20 sampled). Water parameters (dissolved oxygen, pH, water temperature and salinity) were monitored weekly together with growth parameters such as total length, caudal fin length and wet weight. Initial and final fish feed proximate analyses were conducted including fish carcass proximate analyses (protein, fiber, moisture content, and fat). The intention behind measuring growth metrics weekly in the grow-out set-up includes, assessing feed intake and tracking growth which helps evaluate how well the fish are responding to the feed provided, including feed conversion efficiency. In addition this will also allow us to monitor growth rates more consistently, allowed us to detect any trends or changes in growth. Furthermore, this helped us to closely evaluate the health of fish and doing consistent monitoring can indicate the overall health and well-being of the fish. It can also show you a decline in growth which could signal stress, disease, or inadequate nutrition and also allows you to adjusting management practices. Lastly, by doing regular weekly monitoring, this can help determine which is most effective among the treatments.

Description of Sampling

All environmental parameters were sampled in the four cages and monitored weekly, every 7:00 am to check the parameters on water temperature (^{0} T), dissolved oxygen (DO), and pH. For each environmental parameter, the probe was first dipped, then the reading was taken for 10 seconds. The

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next two readings were done in the same way, with the probe being washed with distilled water after reading and before starting in a new cage.

Data Analyses

Data were presented as mean ± standard error of the mean (SEM) prior to testing for normality using Shapiro-Wilk test and variance homogeneity using Levene's test. All data that passed the tests and were subjected to one-way Analysis of Variance (ANOVA). When one of these assumptions were violated, the weight and length data were then log10 transformed to normalize all data encoded. The QQ plot of the distribution was also checked for all the sampled milkfish in the four treatments using Kolmogorov-Smirnov's normality test =0.07, $p<0.0001$ for weight log and for total length log D=0.14, $p<0.0001$ and Levene's test for equality of variances which showed that for weight log, $F=0.89$, $p<0.445$ and for total length log, $F=0.88$, $p<0.45$. Given the large sample size (N=480), and equality of variances, we proceeded with the use of One-way ANOVA for feed treatment comparison. By 12th week there were already 25-31cm sized milkfish and weighs, 171 to 308 g (Figure 1).

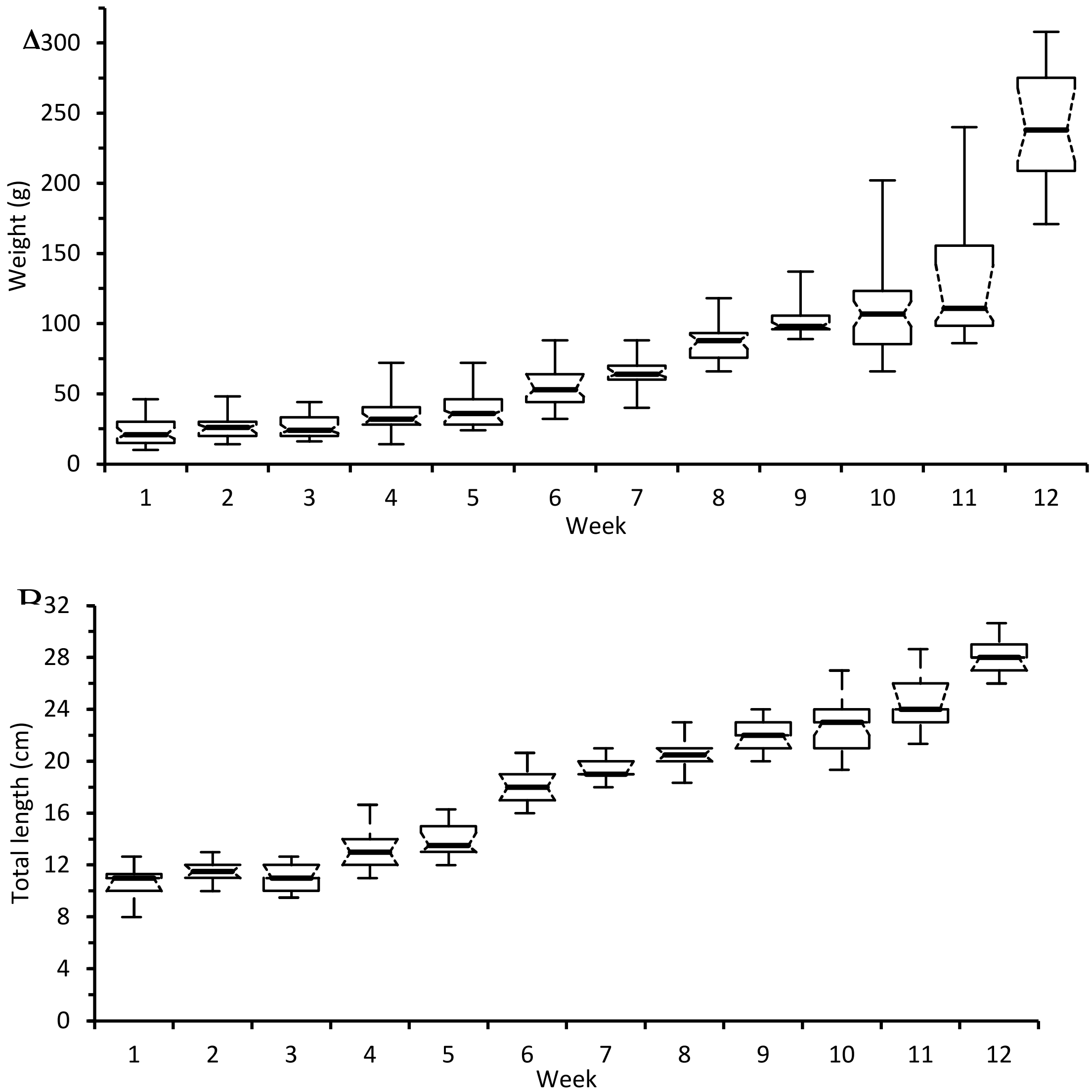

Figure 1. Box plots of change in weight (A) and length (B) of the four treatments in 10 weeks, (connected dots are means through the weeks; whiskers are max and min values).

The following metrics would be vital in assessing the growth, feed efficiency, and overall production performance of milkfish in an aquaculture setting: Feed Intake (FI): In milkfish aquaculture, feed intake plays a critical role in determining how much of the provided diet is actually

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consumed by the fish. Since milkfish are omnivorous, balancing the feed with supplemental algae or natural food sources in ponds is crucial. The formula remains: FI = Total feed provided (g) - Uneaten feed (g) In pond systems, measuring uneaten feed can be done by collecting residual feed from the surface or estimating it based on visual observation during feeding.

Feed Conversion Ratio (FCR): FCR is especially important in milkfish farming as it directly affects the cost-efficiency of the production. The lower the FCR, the more efficiently the fish are converting feed into growth, a key factor in commercial farming profitability. The calculation remains: FCR = Feed intake (g) / Weight gain (g) For milkfish, typical target FCRs are around 1.5-2.0, meaning that 1.5-2.0 kg of feed is required to produce 1 kg of fish.

Protein Efficiency Ratio (PER): Given the mixed diet of milkfish (with a focus on plant-based and low-protein feeds), PER helps gauge how efficiently the fish use dietary protein for growth. With increasing use of plant-based proteins, maximizing PER is important: PER = Weight gain (g) / Protein intake (g) A high PER in milkfish suggests that the feed formulation provides enough protein without being excessive, reducing both feed costs and nitrogen waste.

Weight Gain (WG): Monitoring weight gain in milkfish is essential for tracking growth over the production cycle, especially during critical periods like juvenile to market size.

The formula remains: WG = Final weight (g) - Initial weight (g)

Regular sampling ensures that fish are on target for market weight, which typically ranges from 250 g to 500 g per fish, depending on market demands.

Specific Growth Rate (SGR): Milkfish are fast-growing in warm tropical conditions, so SGR helps farmers monitor daily growth, particularly in response to feed quality or environmental changes.

SGR is a key performance indicator in milkfish farming: SGR = [(ln Final weight - ln Initial weight) / Number of days] × 100 Milkfish farmers often target an SGR of around 2-3% per day, depending on the culture system.

Fulton's Condition Factor (K): In milkfish aquaculture, Fulton's condition factor helps assess the overall health and body condition of the fish. For example, poor K values might indicate undernourishment or stress from poor water quality. K = (Weight (g) / Length^3 (cm)) × 100 Healthy milkfish should have a K value around 1.0 to 1.5, indicating a robust and well-fed fish. Monitoring this ensures optimal health and growth.

Survival Rate (%): Milkfish are resilient but can be sensitive to changes in water quality, disease, or overcrowding, especially in intensive farming systems. Calculating survival rate helps identify mortality trends and potential management issues:

Survival Rate (%) = (Final number of fish / Initial number of fish) × 100 High survival rates (over 90%) are generally expected in milkfish aquaculture, but any significant mortality should be investigated for disease outbreaks or suboptimal conditions.

Yield (kg): Yield is critical in determining the overall success of a milkfish farming cycle. Farmers typically track yield to evaluate the effectiveness of feeding regimes, stocking density, and management practices.

The formula remains: Yield (kg) = Biomass at harvest - Biomass at stocking A high yield is a sign of successful production, often ranging from 3 to 7 tons per hectare in pond culture systems, depending on stocking density.

Monitoring these metrics allows for fine-tuning of feed formulations, management practices, and harvest strategies to achieve optimal results in commercial milkfish aquaculture .

Feed Ingredients and Proximate Analysis

Shown below are percentages of feed composition from the literature (Table 1) as well as from actual proximate analyses (Table 2). Proximate analysis was performed to quantify key nutritional components such as moisture, crude protein, fat, ash, and fiber in the fish feed. This was done using standard procedures:

Crude Protein: Measured using the Kjeldahl method, which determines nitrogen content and calculates protein levels.

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Crude Fat: Determined using Soxhlet extraction, which dissolves fat in solvents for quantification.

Ash Content: Determined by incinerating the sample in a muffle furnace, leaving behind inorganic residue.

Crude Fiber: Measured through sequential acid and alkaline digestion, isolating the fiber fraction.

Quantification of Macro and Micro Elements and Vitamins:

Macro and Micro Elements: Atomic absorption spectroscopy (AAS) was used for elements like calcium, magnesium, potassium, and trace minerals, providing precise concentration measurements. Vitamins: Quantified using high-performance liquid chromatography (HPLC), which separates and identifies individual vitamins based on their chemical properties.

Table 1. These are percentages of the composition and nutrients found in the different diets used in this study.

Composition	Commercial	Taro	Bloodmeal	Banana stem
Protein	26-52%	1.4-3%	81%	2.50%
Fat	6%	0.16-0.36%	0.60%	3.3-8.1%
Moisture content	7-8%	60-80%	4%	15%
Fiber	1.5-2.6%	0.60-1.18%	1.50%	13-70%
Vitamins and Minerals present				
	Calcium=1.40%	Vit C=9mg/100g	Calcium=0.0467%	Magnesium=255mg/100g
	Sodium=2.29%	Thiamine=0.18mg/1	Sodium=0.22%	Sodium=441.1mg/100g
	Phosphoros=0.88%	Riboflavin=0.04mg/	Phosphorus=0.0482%	Phosphorus=137.8mg/100g
	Potassium=1.44%	Niacin=0.9mg/100g	Potassium=0.039%	Potassium=944mg/100g
	Sulphur=1.71%			

Table 2. Actual results from a government laboratory for proximate analyses of the feed used in this study.

	Control	BS	TM	BM
Proximate composition (% dry matter)				
Crude protein [a]	34.07	26.40	17.26	49.39
Crude lipid [a]	6.45	4.36	2.27	1.24
Crude fiber [a]	5.8	4.0	2.5	1.9
Ash[a]	8.47	7.10	4.57	3.67
NFE [b]	45.21	58.14	73.40	43.80

[a] Analyzed values from the Feed Analytical Laboratory (FCAL), Department of Agriculture Region XI, Bago Oshiro, Tugbok District, Davao City, Philippines.
[b] Nitrogen-free extract, computed by difference.

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Results of the Study

Changes in length and weight over the 12 weeks of culture period and monitoring from week 1 to week 12 under different feed treatments were shown below (Figure 2).

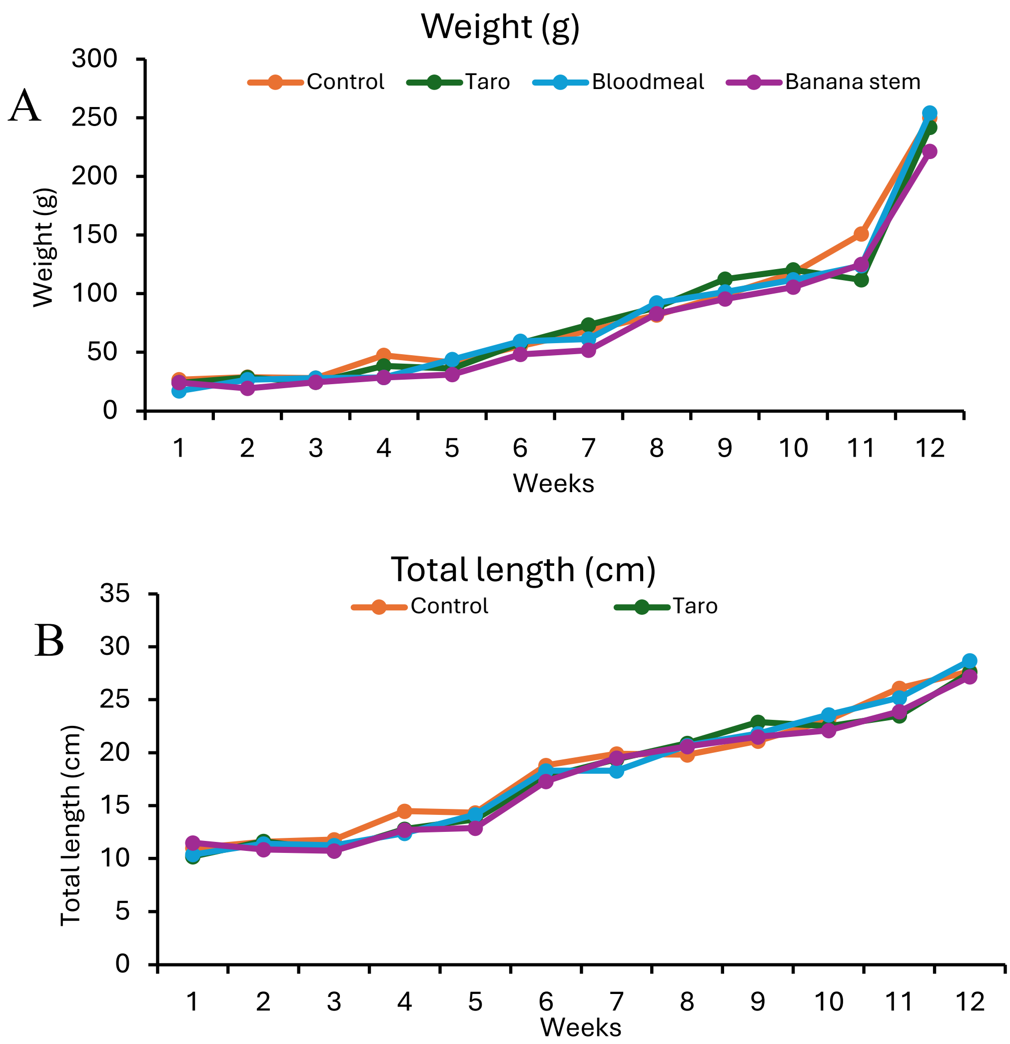

Figure 2. Change in weight (A) and total length (B) in 12 weeks (84 days) of feeding trial of milkfish (*Chanos chanos*) under different treatments e.g. control (commercial), taro (taro+commercial), bloodmeal (formulated feed), banana stem (banana stem+commercial).

The change in weight over the 12 weeks period showed higher increase for the control, taro and bloodmeal treatments especially during the 5th, 6th, 7th and 8th weeks but banana stem treatment also increased during the 8th week with a range already similar to the control (Figure 2A). The change in length was also higher from the 6th week onwards and almost all treatments grew to similar sizes (Figure 2B). In terms of statistics, there were no significant differences between feed treatments from 6th weeks onwards, whether with weight [MS=0.130, df=3, F=1.14, P=0.333] or total length of the treatments [MS=0.008, df=3, F=0.40, P=0.75] (Figure 3).

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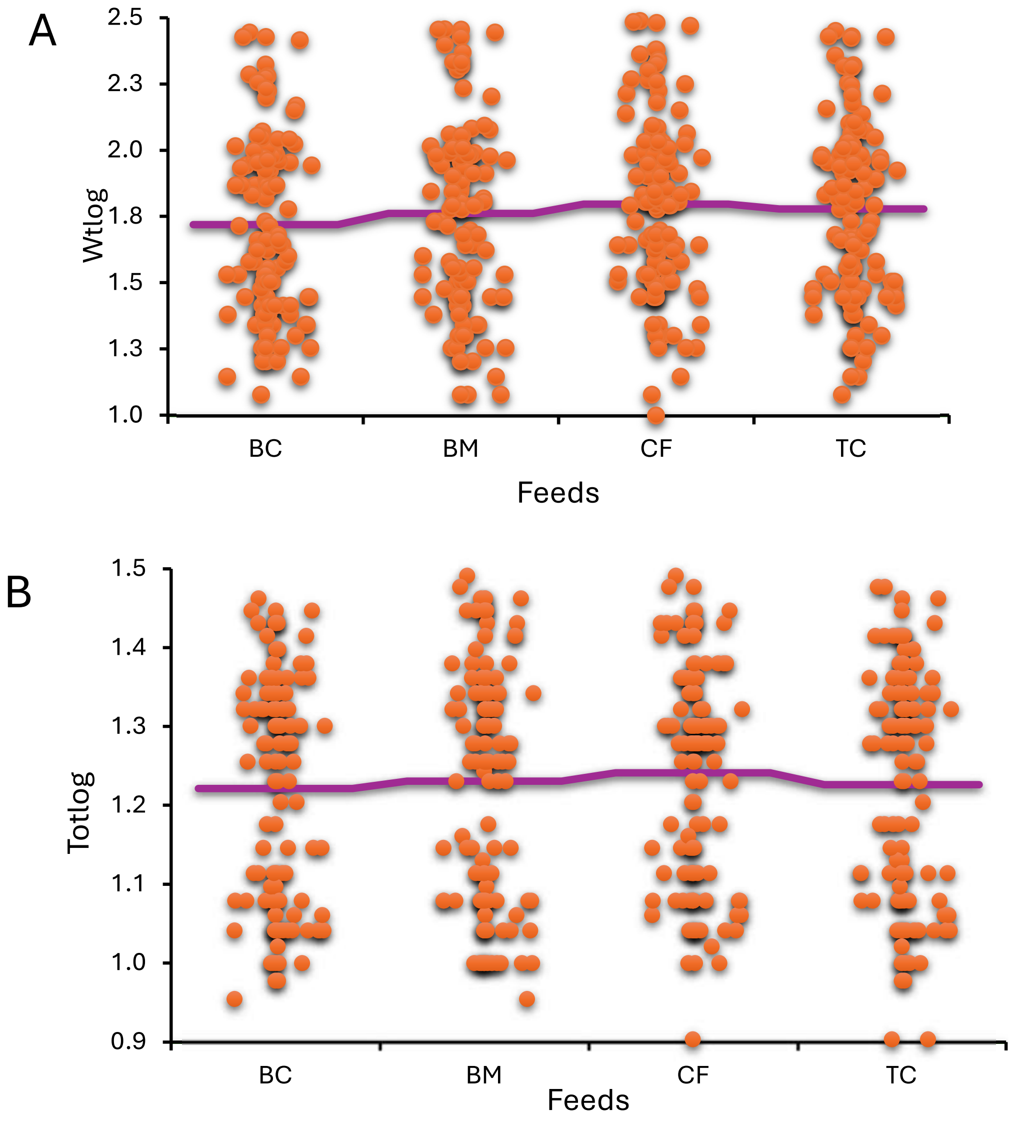

Figure 3. Compares data points on weight (A) and length (B) of the fish sampled in the four treatments and their running mean average which showed no significant differences when compared to the control. (Legend: BC=Banana stem+commercial; BM=bloodmeal; CF=commercial feed; TC=Taro+commercial).

Moreover, the data on the final week (12th week) was also analyzed and compared in terms of the differences per treatment and this showed no differences whether with weight [MS=0.0078, df=3, F=1.53, P=0.223] or length [MS=0.0009, df=3, F=2.02, P=0.123] of the sampled fishes in the treatments.

In Table 3 below you can see the changes in terms of percentages based on average change of weight, daily weight gain and average specific growth rate. In terms of weight gain, the treatments bloodmeal, taro, control, are superior to the banana stem (1476%>1104%>1053%> 859%) in terms of % average weight gain. While for the average daily weight gain this was dominated by bloodmeal (2.82 g), control (2.66 g), taro (2.59 g) and banana stem (2.35 g). This was followed by the final weight gain of bloodmeal>control>taro>banana stem. Despite this the cage culture happened to have moderate survival rates at Control (90%)>Taro (89%)>bloodmeal (87%)> banana stem (77%) for the various treatments.

For the average specific growth rate, bloodmeal (4.55%) and taro (3.96%) are higher than the control (3.93) and banana stem (3.72); For Fulton's Condition Factor which generally assesses the health condition of cultivated fish, the nearer the value to 1 and above, control had the highest value

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(1.17), followed by the taro (1.15), banana stem (1.09), and bloodmeal last (1.07). The FCR ratio shows how efficient the fish can convert a given kilo of feeds to its body weight. Thus a good feed should have a low FCR value which means it takes lower amount of feed to produce one kilogram of fish. In this case, bloodmeal (1.60) was lowest, followed by control (1.65), and taro (1.71) and then banana stem (2.18). In the case of PER or protein efficiency ratio, this has a similar reading when compared to FCR values as this is highly dependent on the crude protein content of the feeds, the lower PER values signify more proteins efficiently converted into bodymass of the fish, bloodmeal (0.97) had lowest value followed by the control (1.31), banana stem (1.36), and then taro last (3.20).

Table 3. Growth parameters, including cost-benefit analysis of the different treatments fed with alternative diets (SEM=standard error of the mean).

Technical basis	Treatments				SEM
	Commercial	**Taro+Commercial**	**Bloodmeal**	**Banana Stem+Commercial**	
Stocking density	3000	3000	3000	3000	-
Culture period (days)	84	84	84	84	-
Initial ABW (g)	18	19.2	17	19.6	0.49
Final ABW (g)	249.93	241.67	253.965	221.185	7.30
Weight gain (g)	223.33	217.67	236.97	196.99	8.31
% Ave. weight gain	1053.34	1103.71	1476.35	898.62	-
Ave daily weight gain (g)	2.66	2.59	2.82	2.35	0.10
Specific growth rate (%)	3.93	3.96	4.55	3.72	0.18
Survival Rate (%)	90	89	87	77	2.98
Feed Conversion Ratio	1.65	1.71	1.60	2.18	0.13
Protein Efficiency Ratio	1.31	3.21	0.97	1.36	0.51
Fulton's Condition Factor	1.17	1.15	1.07	1.09	0.02
Yield (kg)	674.81	645.26	662.85	510.94	37.99
Operational Cost (Php)					
Cost of fingerlings	16,250	16,250	16,250	16,250	-
Labor expense	7,500	7,500	7,500	7,500	-
Cost of feed consumed	52,109.76	32,140.80	44,461.44	27,190.77	-
Cost per kilogram of feeds	52.53	32.4	44.82	27.41	5.73
Total cost of production	75,857.78	55,894.77	68,191.60	50,934.77	7.76
Return (Php)					
Revenue	101,221.65	96,788.84	99,427.30	76,641.00	5.76
Gross Profit	25,363.87	40,894.07	31,235.70	25,706.23	3.54
Gross Profit Margin (%)	25.06	42.25	31.42	33.54	3.55
Cost-Benefit Ratio	2.99	1.37	2.18	1.98	0.33

*Note: Buying price at 150/kg

Cost-Benefit Analysis of Locally Sourced Alternative Feeds

Analysis of cost of feeds when incorporated with locally sourced feed ingredients reveals that there was a great influence on the variation of cost per treatment. It has been identified from Table 3 that pure commercial feeds still has the highest cost per kilogram. The treatment 3 formulated diet containing bloodmeal and soybean meal at 10% and 23% level of composition per kilo is only 14.7% cheaper than commercial feeds. Moreover, treatment 2 and treatment 4 which comprise 50% taro and

50% banana stem and commercial feeds per kilo are 38% and 47% lower in cost per kilogram. Although treatment 4 is the cheapest alternative feed, however, the survival rate of fish, final body weight and average daily gain is lowest resulting to smallest volume of produce and lowest revenue across all treatments. The highest gross profit margin of 42.25% was recorded when milkfish was fed with taro + commercial feeds (treatment 2). This indicates that a significant portion of the revenue is retained as gross profit which suggests less production cost and efficient production. Cost-benefit analysis showed that a better profit and cost-benefit ratio was observed in treatment 2 with a value of 1.37 indicating that the cost outweigh the benefits by 37%, making it a more reasonable option compared to other treatments which values are more than 2.

Discussion

Feed Comparison

The result of the study during the 84 days of grow-out period already showed that there were no significant differences between treatments. While the earlier result of the monitoring pointed to taro and bloodmeal showing higher weights and length and comparable to the control from the 4th to the 5th weeks, the banana stem treatment also caught up with the other treatments by the time it reached 6th week and onwards. This therefore showed a positive result supporting the use of locally available feed materials that could be used as alternative feeds using a mixture or in combination with the commercial feeds available in the market. In previous studies, such as those by (Windarto, 2023) who used maggot meal as a fishmeal replacement, they found out that 35% maggot flour replacement was best for their culture. The replacement was vital as it is the primary protein source used by the fish for its growth (Pratiwi and Andhikawati, 2021). The replacement meal must have a characteristic that is both easily digestible and contains the necessary amino acids for its growth rate and success. Since fishmeal price has been increasing in the market and it has limited source, alternative protein sources are critical for aquaculture species such as milkfish (Agbo et al., 2011). Given the high cost of fishmeal, and feeds in aquaculture operation, it is therefore necessary to find other alternatives to fish meal in formulated feeds (El-Sayed, 2004). The flour used as an alternative to fish meal in this case which was taro, bloodmeal and banana pseudostem seems to have met the protein content needed by the fish so that it induced growth and weight in the cultured fish. When the nutritional profile of the three alternative feeds were evaluated, the bloodmeal had the highest crude protein content (49%), and this was followed by the commercial (34%), banana+commercial (26%) and taro+commercial (17%). Protein is crucial and indispensable for growth and maintenance of life but the diets also contained vitamins which could play critical role in gut health and growth, for instance, vitamin C, riboflavin, thiamine and niacin found in taro play a role in maintaining connective tissues and collagen, in charge of glucose and amino acid breakdown while also keeping the fish healthy (Molina-Poveda, 2016).

Moreover, the presence of calcium, phosphorous, sodium, potassium, and magnesium or macroelements are needed by cultured fish because they could not manufacture these. Absorbed calcium is rapidly deposited as calcium salts in the skeleton but absorbed phosphorus is distributed to all the major tissues: viscera, skeleton, skin, and muscle (Molina-Poveda, 2016). Although perhaps in trace amounts, these minerals are still essential as they are used for the maintenance of the fish, including magnesium for bone density and cartilage formation. Since levels of phosphorus are low in most natural waters, there is a dietary requirement. Meanwhile the use of sodium and potassium are for maintaining homeostasis in the fish. The experiment resulted in better growth for all of the fish cultured although there are lesser values found in the case of banana stem (SGR of 3.72 compared to 4.55 for bloodmeal, and 3.96 for taro and 3.93 for control), still this shows that the feed combination was easily digested by the fish and protein for example was readily absorbed or digested in the case of the bloodmeal. With regards to Fulton’s condition factor which shows how healthy the fish are, most of the fish examined under the different treatments also reached 1, with the control reaching 1.17, taro reaching 1.15, followed by the banana stem at 1.09, and bloodmeal at 1.07. Fulton's condition factor is a valuable metric for assessing the health and overall condition of fish for several reasons, this include being a health indicator. The condition factor provides insight into the general health and well-being of the fish, a higher CF, typically indicates better health and nutritional status, which can correlate with growth potential (Froese, 2006). Second, body condition, Fulton's condition factor helps evaluate the relative fatness or robustness of fish. This can be particularly important in aquaculture, where optimal body condition is linked to growth rates and reproductive success (Jisr et al., 2018). Third, comparative analysis: Using Fulton's condition factor allows for comparisons between different groups of fish or different feeding strategies. It helps identify which diets or conditions promote better health and growth (Morato et al., 2001). And fourth, it is also used for monitoring stress and environmental Impact: Changes in the condition factor can indicate stress due to environmental factors, disease, or suboptimal feeding (De Giosa et al., 2014). Monitoring this metric helps in making necessary adjustments to improve fish welfare. And last, it is used as a support for growth metrics: While growth metrics provide quantitative data on weight gain, Fulton's condition factor offers qualitative insights into the fish's health status, creating a more comprehensive understanding of the aquaculture system.

Our findings demonstrate that the combination using available local ingredients can be used as a replacement when farmers are looking at reducing their feed cost.

Contribution to Circular Economy

In the end, we want to assist local farmers to produce top ingredients that are useful for feed usage. We think that government assistance in providing farmers with peeling and drying machine as well as pulverizing machine could be helpful in realizing a taro flour which can be combined to be used as a feed ingredient, given its usefulness and the available vitamins found in the taro. In the case of the banana pseudostem, this is readily available in the locality which was useful as it can be readily prepared in combination with commercial feeds. Studies on banana pseudostem as an aquafeed is scarce, including its utilization as a natural source of fiber (Provin et al., 2024). The role of banana wastes and its increased utilization as a source of animal feed and fiber should be encouraged and explored further by the government to assist farmers, as it can help contribute in the reduction of greenhouse gas emission. Other agricultural waste products can also be converted to value added products as fertilizers and feeds or bioactive additives (Upadhyay et al., 2024). For instance, cacao husks, coconut wastes, banana peelings, mango peelings and slaughterhouse wastes from bone, to feathers and blood (Macusi et al., 2023a; Wanapat et al., 2024). In addition, other market waste products can be used as a feed for insects such as the black soldier fly (Gasco et al., 2020). Most insect meals come from the black soldier fly (*Hermetia illucens*) which has the potential to reduce the demand for soybean production as it can be utilized in feed replacement (Tahamtani et al., 2021). This has received a lot of attention due to the larvae's ability to convert organic food waste into high-value biomass (van Huis et al., 2013) and rich in protein and fat (Ewald et al., 2020). Moreover, other food waste materials that contain high protein, fat, and carbohydrates, can also be very valuable in the production of prebiotics, animal feed, and cosmetics (Ganesan et al., 2024; Wong et al., 2016). Thus due to the precarious status of global fisheries, the aquaculture sector is pressured to move away from fishmeal (FM) and fish oil (FO) as feed ingredients, toward more sustainable alternatives (McLean, 2023). In this country, participation in the agricultural sector, such as farming, fisheries and raising livestocks are the main livelihoods of the poorest of the poor. This population when taught proper waste evaluation and techniques and given funds to improve their efficiency of agricultural production and convert agricultural wastes such as banana stem, fruit peels and cacao pods and coconut husks into livestock feed, can reduce environmental impact of agricultural activities (Sehgal and Sharma, 1993; Wong et al., 2016). Applying common principles of circular economy will help reduce the impact on natural resources and economically uplift society by enhancing the quality of life and creating new jobs (Mujtaba et al., 2023; Najar et al., 2024).

Cost-Effective Alternative Feeds

The result of the financial assessment of the feed cost clearly showed that commercial control treatment was still more costly compared to the alternative feeds, including the fishmeal free

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bloodmeal. There was higher profit margin with regards to the taro treatment (42.25), followed by the banana stem (33.55) and bloodmeal (31.42), when compared to the control (25.06). The cost-benefit ratio follows the same with Taro having the lowest ratio at 1.37, followed by the banana stem at 1.98, all of these provide us an overview that the alternative feeds are much better compared to the control. Considering that one of the treatments was readily available in the area at no cost to the researchers, we assumed that the cost would be from electricity incurred by the machine shredder. Thus, we used an approximation of processing cost which was done by identifying the power rating of the shredder device, determining the duration of shredding the banana stem and calculating the energy consumption. In the case of the taro, this was more labor intensive as a farmer must peel the taro, clean and chop it and soak overnight then dry under the sun. We assumed that the cost of peeling and drying would be the labor cost incurred per day of peeling and drying the taro and operating a pulverizing machine. On the other hand, bloodmeal requires formulation, because it is a replacement of the fishmeal diet together with other sourced ingredients. The ingredient can be easily found in crude or dried blood from slaughterhouse but this may not be hygienically sourced or clean compared to buying it commercially. Still, the cost benefit ratio showed that bloodmeal has better CBR compared to the control (2.18 vs 2.99). Our study has proven that fishmeal-free and other alternative feeds can replace the use of pure commercial feeds in milkfish aquaculture.

Conclusion

The results of the study showed that farmed milkfish under grow-out culture with adjusted feeding rates based on average body weight using the four treatments tested in this study demonstrates possible alternative usage for milkfish farmers who wanted to reduce their feed costs. The pursuit and push to use agricultural wastes products, towards its transformation into feed (and fiber and fuel) components can help realize the SDG goals of the Philippine government in the long-term where it applied the circular economic principle. There is an improved economic performance with integration of taro and commercial feeds in milkfish diet. This demonstrates sustainability and viability of taro meal as a promising alternative source to minimize the feed cost in the aquaculture industry. The study was limited in terms of cage replications and multiple site testing but given the number of sample sizes found in each cage for the treatments, the results provided were still robust and useful for practical applications. Future grow-out experiments should include more cage replicates, including treatments and multiple site testing, and including other aquaculture species such as tilapia and white shrimps.

Appendix

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Figure A1. Feed preparation for the four treatments: Taro is cleaned and peeled (A) then later soaked and dried under the sun (B), taro flour produced from dried taro chips (C); banana stem is cut and chopped to pieces (D) and then shredded and dried (E), and powderized banana stem (F).

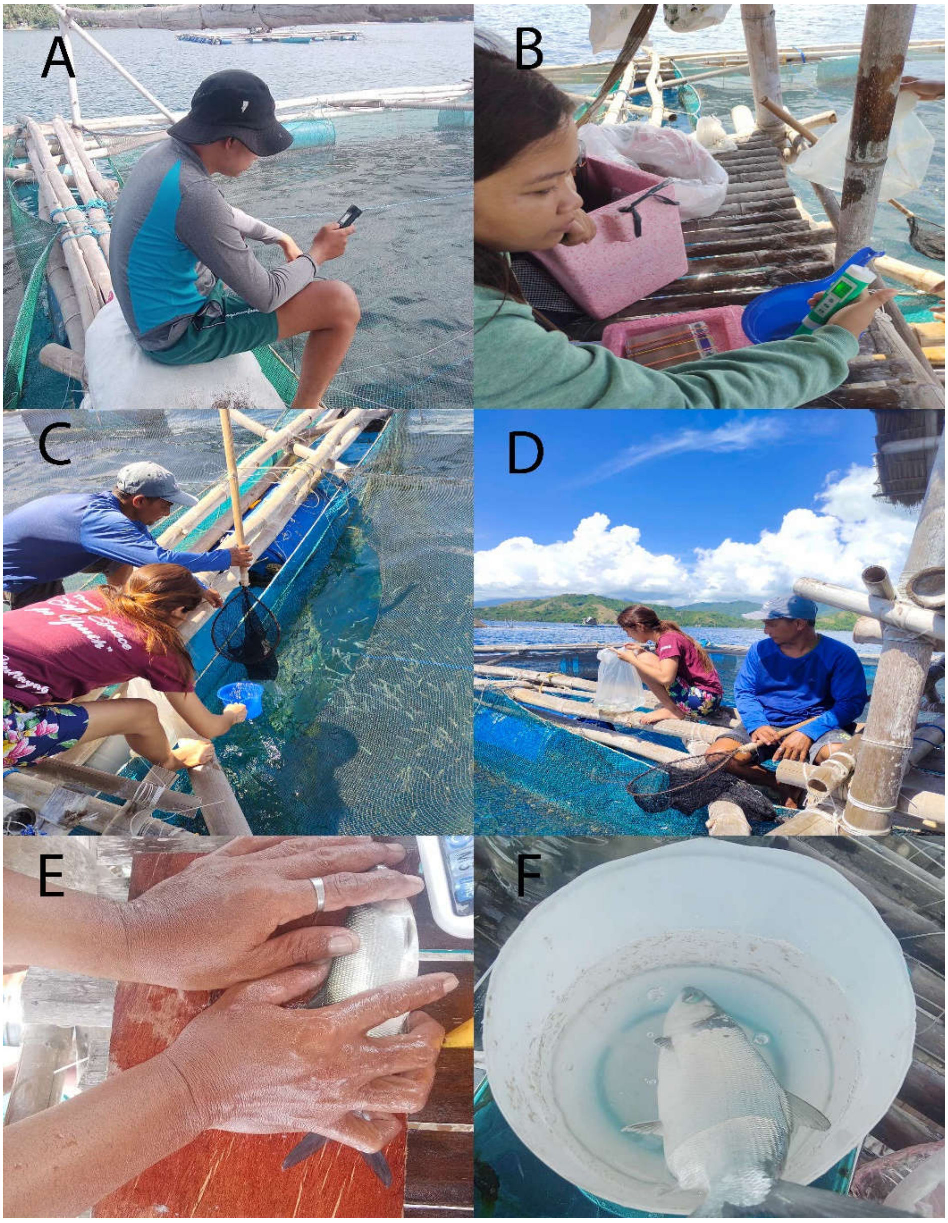

Figure A2. Environmental parameters are gathered weekly during the early morning hours (6-7:00 am; A, B); then fish samples are collected using a scoopnet (C, D) and then their length (E) and weight taken (F) and fish sampled are then released back to the fish cage.

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