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STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS IN USING LOCAL RAW MATERIALS FOR TILAPIA FEED FORMULATION IN JAMAICA

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ABSTRACT

The aquaculture sub-sector in Jamaica has faced many challenges over the years, such as land availability, water quality, limited capital investment, praedial larceny, production costs, and competition from cheap imports. The largest source of production costs is fish feed. To achieve a more economically efficient and environmentally sustainable aquaculture industry in Jamaica, this study assessed the strengths, weaknesses, opportunities, and threats (SWOT) associated with producing tilapia feed from local raw materials. Available and potential raw materials, such as poultry meal, fish offal meal, lobster heads meal, conch by-products meal, wheat mill run, distillers/brewers' grain, peanut seed, duckweed, cassava leaves meal, cassava waste, brewery spent grain (BSG), and brewery spent yeast (BSY), were identified. The raw materials were quantified, and most were found to be available in sufficient quantities for use in feed formulations. A diet formulator was used to formulate a diet using some of these raw materials, and the diet met or exceeded all the nutritional requirements of tilapia. Special attention was placed on the protein content of the potential diet, as protein is the most essential and expensive component of a fish diet. The potential diet met or exceeded all essential amino acid requirements for tilapia. The economic viability of the potential diet was also assessed and compared with other locally available feeds (both local and imported products). It was found to be cost-effective. Costing was done using all the diets (BioMar, South-Fresh, Best Dress feeds, and formulated diet) for production for one year using the same stocking density of 10,000 per pond, with a mortality of 20%. The results showed that the cost of feed per kg of fish produced was USD 1.85/kg (South-Fresh feeds), USD 3.43/kg (BioMar feeds), USD 3.62/kg (Best Dress feeds), and USD 2.30/kg (locally formulated diet). There is a high volume of raw material available for fish feed and strong market demand for tilapia, making the estimated cost of producing local fish feed both economically effective and environmentally sustainable.

Key words: Tilapia aquaculture, feed formulation, local raw materials, SWOT analysis, alternative feed ingredients, Jamaica.

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1 INTRODUCTION

1.1 Background and Rationale

The aquaculture sub-sector in Jamaica has faced many challenges over the years, such as land availability, water quality, limited capital investment, praedial larceny (theft of fish), production costs, and competition from cheap imports (Aiken et al. 2002). Since 2008, there has been a sharp decline in production due to the exit of a major investor, Jamaica Broilers Ltd. Jamaica Broiler lost its export market to the US due to competition from cheap imports from Asia, particularly China. Most of the 189 farmers who were in production at the time were contracted to Jamaica Broilers and found themselves unable to sell the fish on their farms. Therefore, most of them became financially challenged and exited the industry.

The National Fisheries Authority (NFA), established in 2018 as a feature of the Fisheries Act (2018), is responsible for the sustainable development of Jamaica's fisheries. The NFA is taking an "ecosystem-based approach" to managing Jamaica's fisheries (CANARI, 2020). The NFA's strategic plan to increase tilapia production to 3,400 metric tons (MT) by 2026 is attainable, but the high cost of production, particularly the cost of feed, could derail this plan if not urgently addressed.

As part of their strategy, the NFA is currently conducting preliminary work in preparation for the construction of a biosecure hatchery to increase tilapia seed stock production from 1.3 million to 5 million annually by the end of 2025. Based on industry standards, 5 million seed stocks should produce approximately 1,225 MT of tilapia at farm gate. Currently, there are 98 active tilapia farmers producing fish on approximately 284 hectares of ponds. However, there are approximately 994 hectares of ponds available for local production, with additional land available for expansion (NFA, 2022). In 2007, there were approximately 189 farmers producing 5,600 MT of tilapia, and in 2021, there were approximately 84 farmers producing 869 MT (NFA, 2022). The aim is to return to that level of production by 2030.

Fish have unique nutritional requirements, and researchers are still discovering beneficial diets for fish, including tilapia. Tilapia, one of the most important aquaculture resources, continues to receive considerable attention worldwide. Tilapia is known for its ability to adapt to different environments and diets and is key to the sustainability of global aquaculture.

The cost of fish feed is one of the main challenges facing aquaculture in Jamaica. The cost is between 60 and 70 percent of the production cost (NFA, 2022). This is mainly due to the importation of ingredients to formulate feeds or expensive feeds. Currently, Jamaica has one feed manufacturer, Best Dressed Feed Mills. According to the Food and Agriculture Organization (FAO), "The feed is reported to contain 28 percent protein and costs USD 0.57/kg to USD 0.68/kg, depending on whether it is formulated as pellets or a mash." Most of the ingredients in the diet are imported and include fishmeal, soya, corn, wheat flour, vitamins, and minerals (FAO, 2022). In 2021, the company reported that it produced approximately 1,896 MT of tilapia feed. The average price in 2021 was USD 0.75/kg in farm stores (NFA, 2022). Despite the high feed costs, tilapia production remains a profitable venture in Jamaica.

Since 2021, four different types of tilapia feed have been imported from BioMar Aqua Corporation Products, Costa Rica. The feeds contain 60%, 42%, 36%, and 29% protein. Based on data collected by the NFA extension staff, producers using this feed have considerably reduced the production time, making tilapia production viable for those farmers despite the high cost of the feed. Based on recent data, the price of tilapia at the farm gate is approximately USD 6.40 per kg, and the estimated cost of production is between USD 3 and 4.25 per kg (NFA, 2022).

The need to increase productivity while lowering production costs is the main reason for this study's focus. Since 2020, Jamaica has experienced an increased demand for tilapia. This is believed to be driven by more people working from home, scarcity of marine catch, promotion of tilapia by the NFA, and increased acceptance by the public. According to FAO (2019), "Jamaican fish consumption was approximately 25.8 kg/year in 2017, but the supply is significantly dependent on imports, accounting for about 79% of all fishery products consumed domestically that year (FAO, 2019). In 2017, imports of fish and fishery products were valued at USD 116.6 million, and exports were valued at USD 14.7 million. The decline in capture fisheries over the past few years has created an excellent opportunity for aquaculture production to meet the demand for fish in Jamaica.

This study undertakes a SWOT analysis to identify the strengths, weaknesses, opportunities, and threats associated with utilising locally available raw materials in tilapia feed in Jamaica, with the goal of increasing the productivity of the aquaculture sub-sector.

1.2 Research Objectives

Many studies have highlighted the challenges facing the aquaculture sub-sector in Jamaica (Aiken et al., 2005; FAO, 2022). Jamaica is currently reviewing the 2008 draft fisheries policy, and many recommendations have been made. However, a holistic approach is necessary to address the decline in aquaculture production. Tilapia production accounts for approximately 98% of all aquaculture; however, the production volume is still limited, indicating the need for improved productivity. Increased aquaculture production will enhance Jamaican food security while improving Gross Domestic Product (GDP). Efforts to utilise domestic sources may increase production sustainability.

1.2.1 Objectives

The main goal of this study is to assess the strengths, weaknesses, opportunities, and threats (SWOT) associated with the use of local raw materials in tilapia feed formulation and production in Jamaica.

To accomplish this general objective, this study aims to achieve the following specific objectives:

1. Literature review of aquaculture in Jamaica, the Caribbean, and farther afield.
2. Analysis of local raw materials available for tilapia feed.
3. Evaluate the nutritional profile and availability of raw materials.
4. Assess the economic viability of producing feed from local raw materials.

2 LITERATURE REVIEW

2.1 World Aquaculture Production

According to the FAO, “global production of aquatic animals was estimated at 178 million tonnes in 2020, a slight decrease from the all-time record of 179 million tonnes in 2018” (Table 1 and Figure 2). Capture fisheries contributed 90 million tonnes (51%) and aquaculture 88 million tonnes (49%). Aquaculture production was estimated to reach 122.6 million tonnes, valued at USD 281.5 billion the same year, with aquatic animals estimated at 87.5 million tonnes and algae at 35.1 million tonnes (FAO, 2022).

Asia continues to be the world leader in aquaculture production, contributing approximately 92 percent of all production, with China being the largest producer. However, there has been a significant expansion in other regions, such as Chile and Norway (FAO, 2022). Fisheries and aquaculture are significant sources of employment, with an estimated 58.5 million people employed in the primary sector. Approximately 600 million livelihoods are estimated to be directly or indirectly impacted by aquatic production, which is important for food security and poverty alleviation (FAO, 2022).

Fish meal is the preferred source of protein in tilapia feed because it contains all the essential amino acids required for optimal growth and health. However, its production has been decreasing over the years owing to the overexploitation of fish stocks and increased direct human consumption of forage fishes. Fishmeal production has declined from a peak of approximately 7.5 million metric tons in 1994 to 6 million MT in 2020 (FAO, 2020) (Figure 1). Capture fish is the main source of fish meal, and a decline in this sector will directly impact fish meal production.

Tilapia is the second-largest fed species group among freshwater fish in aquaculture, with an average production growth rate of 11.3% per year from 1998 to 2008 (FAO, 2010a). According to Tacon, Hasan, and Metian (2011), “The percentage of total fed tilapia production based on commercial feeds increased from 70% in 1995 to 83% in 2008, with feed production increasing from 0.99 to 3.95 million tonnes. The volume of feed produced for tilapia culture was estimated to reach 12.0 million tonnes by 2020.” FAO data suggest that aquaculture production will continue to increase as capture fisheries decline. Cost-effective aquaculture production is a challenge and has been a concern for producers worldwide.

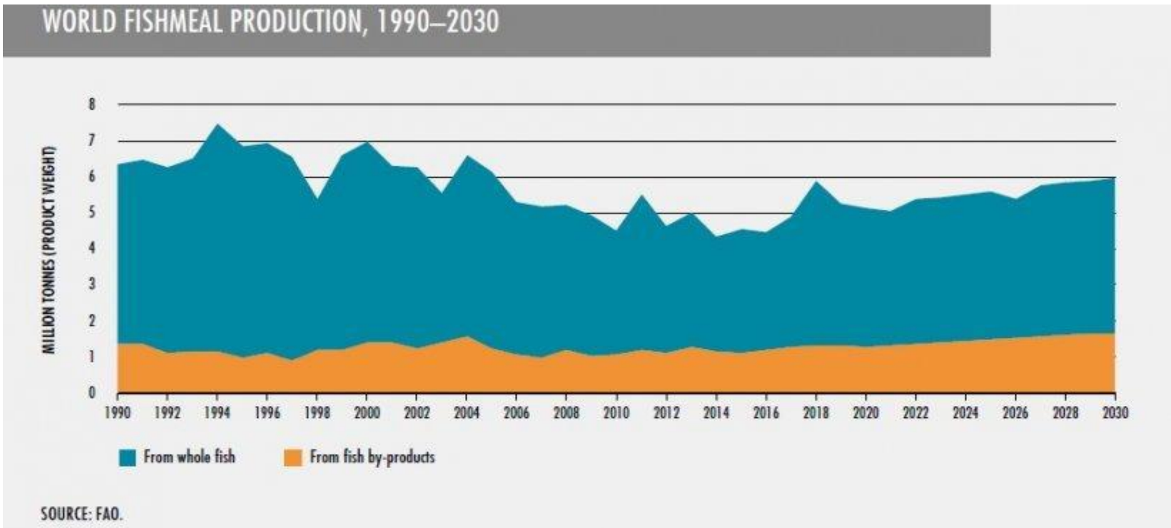

Figure 1 World Fishmeal Production (1990- 2030)

The use of captured fish as a protein source for aquaculture is not sustainable if the fish can be directly utilised for human consumption. According to the FAO, "of the overall production of aquatic animals, over 157 million tonnes (89 percent) were used for human consumption. The remaining 20 million tonnes were destined for non-food uses, to produce mainly fishmeal and fish oil (16 million tonnes of fish or 81 percent) (Figure 3). The need for alternative sources of raw materials is critical for the sustainable development of the aquaculture sub-sector.

Table 1 World fisheries and aquaculture production, utilisation and trade.

	1990s	2000s	2010s	2018	2019	2020
	Average per year					
	Million tonnes (live weight equivalent)					
Production						
Capture:						
Inland	7.1	9.3	11.3	12.0	12.1	11.5
Marine	81.9	81.6	79.8	84.5	80.1	78.8
Total capture	**88.9**	**90.9**	**91.0**	**96.5**	**92.2**	**90.3**
Aquaculture:						
Inland	12.6	25.6	44.7	**51.6**	**53.3**	**54.4**
Marine	9.2	17.9	26.8	**30.9**	**31.9**	**33.1**
Total aquaculture	**21.8**	**43.4**	**71.5**	**82.5**	**85.2**	**87.5**
Total world fisheries and aquaculture	**110.7**	**134.3**	**162.6**	**178.9**	**177.4**	**177.8**
Utilization[2]						
Human consumption	81.6	109.3	143.2	156.8	158.1	157.4
Non-food uses	29.1	25.0	19.3	22.2	19.3	20.4
Population (billions)[3]	5.7	6.5	7.3	7.6	7.7	7.8
Per capita apparent consumption (kg)	14.3	16.8	19.5	20.5	20.5	20.2
Trade						
Exports – in quantity	39.6	51.6	61.4	66.8	66.6	59.8
Share of exports in total production	*35.8%*	*38.5%*	*37.7%*	*37.3%*	*37.5%*	*33.7%*
Exports – in value (USD 1 billion)	46.6	76.4	141.8	165.3	161.8	150.5

Note: [1] Excluding aquatic mammals, crocodiles, alligators, caimans, and algae. Totals may not match due to rounding; [2] Utilisation data for 2018–2020 are provisional estimates; [3] Source of population figures: United Nations. 2019. 2019 Revision of World Population Prospects. In: UN. New York. Cited 22 April 2022. https://population.un.org/wpp. **Source**: FAO.org, 2022.

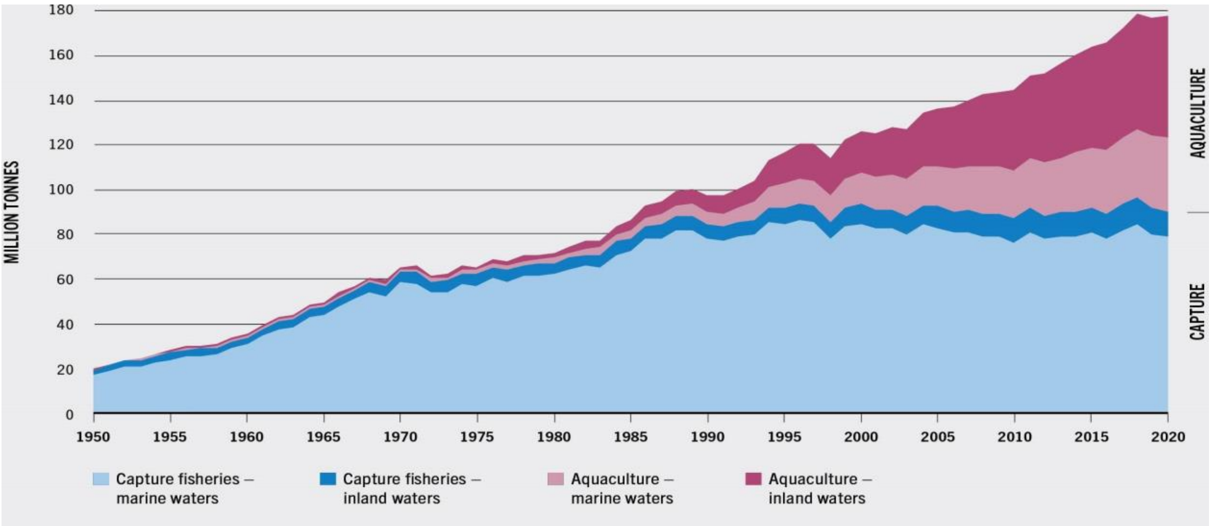

Figure 2 World fisheries and aquaculture production from 1950-2020, excluding aquatic mammals, crocodiles, alligators, caimans and algae. Data expressed in live weight equivalent (FAO, 2022).

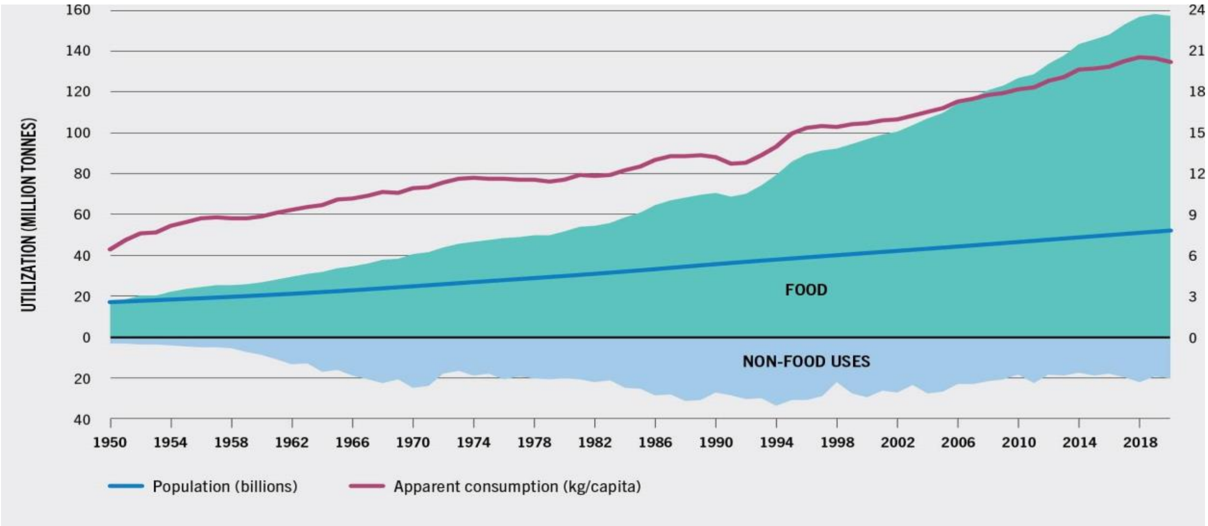

Figure 3 World fisheries and aquaculture production: utilisation and apparent consumption compared to the human population. The data exclude aquatic mammals, crocodiles, alligators, caimans, and algae. Data expressed in live weight equivalent (FAO.org).

2.2 Aquaculture in Jamaica and the Caribbean

Jamaica is the third largest island in the Caribbean Sea. It is located 898 km southeast of Miami, United States, and 144.6 km south of Cuba. Jamaica has a land mass area of 10,991 km^2, a coastline of approximately 1,022 km, and an Exclusive Economic Zone (EEZ) of 274,000 km^2 (FAO, 2022).

Aquaculture in Jamaica began in 1976 through a Fisheries Project by the Government of Jamaica/USAID Program, aimed at evaluating and promoting the farming of freshwater fish (Hanley, 2005). Commercial production began in 1977 with *Oreochromis mozambique* and expanded rapidly in the 1980s. Nile tilapia (*Oreochromis niloticus*) was introduced in 1978 as it was proven to be a better fish for pond culture. Grass carp (*Ctenopharyngodon idellus*), mirror carp (*Cyprinus carpio var specularis*), silver carp (*Hypophthalmichthys molitrix),* and bighead carp (*Hypophthalmichthys nobilis*) were imported from Panama in 1981 (Hanley, 2005; FAO, 2022).

The aquaculture industry in Jamaica is divided into two subsectors: food and ornamental fish. The food fish subsector consists primarily of red hybrid tilapia, crustaceans (*Penaeus vannamei* (white leg shrimp), and *Macrobrachium rosenbergii* (freshwater shrimp), and mollusks (*Crassostrea rhizophorae* (mangrove oyster). The ornamental fish subsector produces a variety of ornamental fish species, such as *Pterophyllum scalare* (freshwater angelfish) and *Crassius auratus* (goldfish), for export (FAO, 2022). Currently, there are no producers of *P. vannamei* (white leg shrimp) and *M. rosenbergii* (freshwater shrimp) in Jamaica; however, the NFA hopes to encourage their production by setting up a hatchery facility to provide post larvae to farmers.

Aquaculture production in Jamaica moved from being primarily a subsistence venture in 1980, with 63 farmers producing approximately 32.6 tons per year, utilising 58 hectares of ponds, to a commercialised industry in 2006/7, with 189 farmers utilising approximately 1,100 hectares to produce 8,019 tons per year (FAO, 2022). Approximately 70% (5,600 Mt) of this production was tilapia farming. However, we have seen a rapid decline to just 869 tons of tilapia in 2021, with 84 active farmers (NFA, 2022; Figure 4). This decline can be attributed to the sharp increase in production costs, competition from cheap imports, loss of markets, little or no available capital for investment, and high startup costs (Aiken et al., 2002). Basa (*Pangasianodon hypophthalmus*) production started in 2016 but was discontinued because the only producer (Algix Jamaica Ltd.) was unable to compete with cheap imports (NFA, 2022). Most aquaculture occurs on the south coast of the island, mainly (83%) in the central plains (St. Catherine and Clarendon), where the farming conditions are the best. A 2021 survey conducted by the NFA showed that of the 84 farmers involved in aquaculture production, 66 (78%) had small-sized (0-2.02 hectares) farms, 10 (12%) had medium-sized (2.4-5.26 hectares) farms, 4 (5%) had medium-large-sized (8-11 hectares) farms, and only 4 (5%) had large-sized (over 24 ha) farms (NFA, 2022).

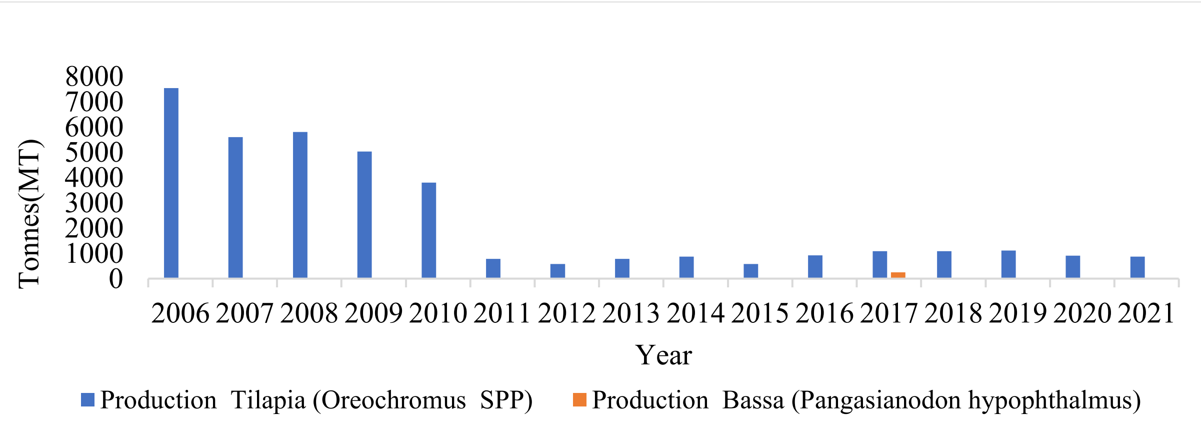

Figure 4 Tilapia (blue) and Basa (Pangasianodon hypophthalmus, orange) production in Jamaica between 2006-2021 (NFA, 2022).

Jamaica has been one of the leading aquaculture producers in the Caribbean; however, over the past few years, the Dominican Republic and Haiti have recorded higher levels of production (World Bank, 2022; Wurmann, C. Soto, D., Norambuena, R., 2022). Cuba has always been the leader, with most of its production being silver carp and tilapia. Aquaculture production in the Caribbean continued to decline in 2020; however, Haiti and the Dominican Republic recorded an increase (Table 2). Aquaculture production in the Caribbean is still in the developmental stage. Haiti received help from the FAO to increase its tilapia production in response to the devastating earthquake in 2010 (Wurmann, C. Soto, D., Norambuena, R., 2022). Most small island states have little or no production. According to CFRM (2014), "Between 2000 and 2011 the cumulative production volume from aquaculture was 71,044 MT for Belize while that for Jamaica was 52,123 MT." The Dominican Republic had the next largest aquaculture production of 17,089 MT over the same period. Despite this fact, the Dominican Republic and Jamaica were the largest importers of fish and fish products. Only the Bahamas, Cuba, Curacao and Grenada reported a positive seafood trade balance between 2000 and 2018 (Wurmann, C. Soto, D., Norambuena, R., 2022).

Caribbean aquaculture production has fallen by an average of one percent per year from 2000 to 2018 (Table 3), with a total production of 34,311 tons in 2018 (Wurmann, Soto, and Norambuena, 2022). Most of the production is tilapia and carp farming. However, striped catfish (*Pangasianodon hypophthalmus*) are also cultured in the Dominican Republic. The main source of aquaculture production in the Dominican Republic is Carp in polyculture with white-leg shrimp (*Litopenaeus vannamei*). Shrimp cultures (marine and freshwater) experienced a significant decline in 2009, mainly due to disease and the exit of producers (CRFM, 2014). Some efforts are being made to increase the production of *Macrobrachium rosenbergii* (giant river prawn) in Jamaica and Puerto Rico (NFA, 2022; Wurmann, C. Soto, D., Norambuena, R. 2022).

Seaweed farming has been a viable option over the years, with *Gracilaria* and *Eucheuma* species, which are traditionally consumed in the Caribbean, being the most likely candidates for production. In 2018, Saint Lucia was ranked among the top ten seaweed producing countries of the subregion (Wurmann, C. Soto, D., Norambuena, R., 2022).

Table 2 Aquaculture Production across the Caribbean in 2020 (World Bank, 2022).

Country	**Production (MT)**
Antigua and Barbuda	20
Bahamas	6
Barbados	26
Cuba	26,200
Dominica	0
Dominican Republic	2,680
Grenada	23
Haiti	1,560
Jamaica	918
Saint Kitts and Nevis	2
Saint Lucia	92
Saint Vincent and the Grenadines	13
Trinidad and Tobago	4
Total	31,544

Table 3 The top 10 aquaculture producers in the Caribbean between 2010 and 2018 (FAO, 2020c). CAGR: compound annual growth rate.

Country	2010 rank	2018 rank	2010	2018	2018 (% Caribbean)	CAGR 2010 – 2018
Cuba	1	1	31, 422	28 628	83.40%	-1.20%
Dominican Republic	3	2	1 280	2 500	7.30%	8.70%
Jamaica	2	3	3 952	1 616	4.70%	-10.60%
Haiti	4	4	360	1 400	4.10%	18.50%
Martinique	5	5	82	49	0.10%	-6.20%
Barbados	12	6	2	26	0.10%	37.50%
Guadeloupe	9	7	11	24	0.10%	10.20%
Puerto Rico	6	8	17	20	0.10%	2.10%
Saint Lucia	11	9	6	15	0.00%	13.40%
Antigua and Barbuda	16	10	--	10	0.00%	--

2.3 SWOT Analysis

Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is a very informative tool frequently used to assess strengths and weaknesses (internal factors) of a company or industry (in this case, tilapia production in Jamaica) and the potential opportunities and threats (external factors) of the operating environment that can have an impact on the sector, such as consumers, government policy, and markets (Radheyshyam 2001; Görener et al. 2012; Rimmer et al. 2013; Babatunde et al., 2021). SWOT analysis is a framework that is very useful for identifying challenges, helping with planning and decision-making, and informing precautionary measures that should be taken to increase aquaculture production (Babatunde et al., 2021). The main aim of analysing external opportunities and threats is to evaluate the opportunities that can be harnessed and avoid threats from an uncontrollable external environment. The analysis of internal strengths and weaknesses is done to appraise the internal activities of an industry or sector (Babatunde et al., 2021; Chang and Huang, 2006). Figure 5 provides an example of a SWOT analysis.

The idea of using a SWOT analysis, in this case to look at the feed challenges in Jamaica, could be considered an innovative way to identify the strengths, weaknesses, opportunities, and threats that exist or are likely to become a reality. Jamaica has some unique challenges, but there are several strengths and opportunities that can be leveraged. In 2022, a report titled "Consultancy to Assess the Local Availability of Fish Feed and Prepare a Strategy and Action Plan for Improving Accessibility to Affordable Quality Fish Feed" was prepared for the NFA as part of the "Promoting Community Based Climate Resilience in the Fisheries Sector Project" (World Bank Project). This report highlights several important factors affecting Jamaica's ability to access good-quality, affordable fish feed for both food and ornamental fish. However, little attention has been paid to the potential opportunities that could be realised.

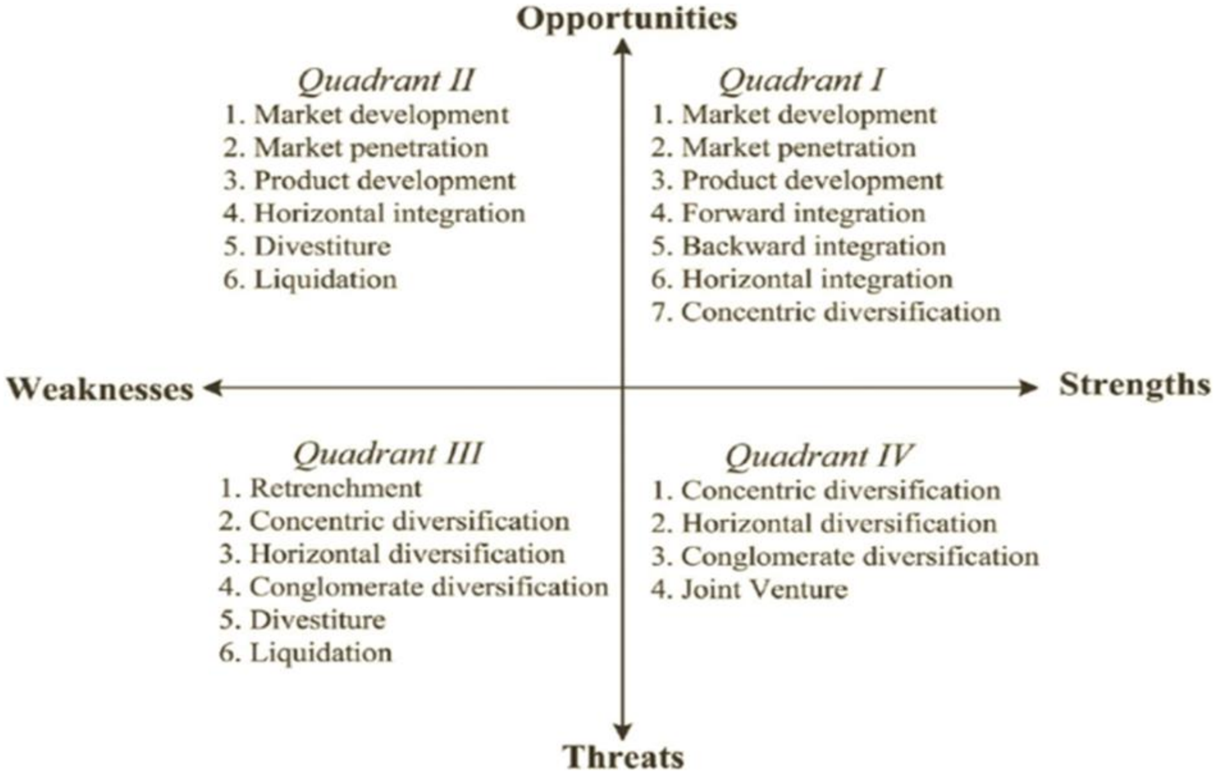

Figure 5 Quantified SWOT analysis and strategic matrix (Chang and Huang 2006).

3 METHODOLOGY

3.1 Study Design

SWOT analysis was used as a tool to identify the strengths and weaknesses (internal factors) and opportunities and threats (external factors) involved in using local raw materials to formulate tilapia feed for fish farming in Jamaica. Data for this study were collected in two ways: 1) Primary data - interviews conducted with current and prospective feed manufacturers as well as experts in the field of fish nutrition and 2) Secondary data - a review of existing literature on the use of alternative raw materials in fish feed, using reliable sources such as FAO, World Bank, feedipedia.org, and local feed manufacturers.

Relevant questions identified in the SWOT analysis were carefully studied, and all possible solutions were discussed. These answers are the basis for deciding whether the strengths and opportunities outweigh the weaknesses and threats to the viable use of local raw materials for producing feed. The following socioeconomic questions were explored:

1. Current and potential levels of production of raw materials
2. The likely cost of raw materials and potential cost of production.
3. Feasibility of introducing new equipment for feed manufacture.
4. Attitude of current and prospective feed manufacturers toward the idea of using these raw materials.
5. How long would it take to start production?

The first part of this study is a literature review, where information was analysed according to the SWOT approach to assess internal factors (Strengths and Weaknesses) and to harness external factors (Opportunities and Threats) that could apply to Jamaica's situation. The nutritional compositions of alternative domestic raw materials and their possible combinations for formulating suitable feeds for tilapia were assessed. The cost of production using potential raw materials such as duckweed, poultry meal, and wheat millings will be estimated and compared with the current cost of tilapia feed production locally.

4 AVAILABILITY AND SUITABILITY OF LOCALLY AVAILABLE RAW MATERIALS FOR TILAPIA FEED FORMULATIONS

4.1 Raw materials for Tilapia feed

Several types of raw materials are currently used for feed formulations for tilapia worldwide (do Nascimento et al., 2020; Kubitza, 2019; Munguti et al., 2006). The raw materials used are dependent on several factors, such as the nutritional requirements of fish, nutritional value of raw materials, stage of development of fish, digestibility, and availability of raw materials (do Nascimento et al., 2020; Kubitza, 2019; Montoya-Camacho et al., 2018; Creswell, 2005; Koprucu and Ozdemir, 2005; Fasakin et al., 2001). Generally, raw materials are selected to meet the basic nutrients, such as proteins, fats, carbohydrates, vitamins, and minerals. However, tilapia feeds are not only used to meet the growth requirements of fish but also to develop the immunity of fish to fight against stress and diseases (Kubitza, 2019). Table 4 and Table 5 provide examples of raw materials currently used to formulate feed worldwide.

Research to identify other sources of raw materials as tilapia feed ingredients continue as the demand for feed increases. This is driven by the need for alternative sources of protein other than fishmeal, which is the most expensive ingredient in tilapia feed (El-Sayed, 2006). Several local raw materials have been used in Africa and Asia, and they have become an important part of the nutrition, especially for medium-to low-income producers that are mostly involved in extensive and semi-intensive production of tilapia. The nutritional value of local raw materials has been evaluated and found to be suitable as tilapia feed ingredients (Munguti et al., 2012). The formulation of feed on farms is vital to these producers as they seek to minimise production costs and maximise the use of locally available resources. This has also resulted in job creation and improved the sustainability of fish farming.

The potential use of agricultural by-products in fish feed in Caribbean countries (Figure 6) was assessed, and opportunities for development and collaboration in feed production were identified (CRFM, 2014). The movement of these raw materials is facilitated by the Caribbean Single Market and Economy (CSME) trade agreement. Increased productivity in Jamaica is critical for increased production in the Caribbean, as Jamaica has the basic infrastructure and technical expertise to facilitate this. Domestic commercial fish feed production requires a considerable volume for the product to be economically feasible. Additional markets in the Caribbean islands would be beneficial for these establishments.

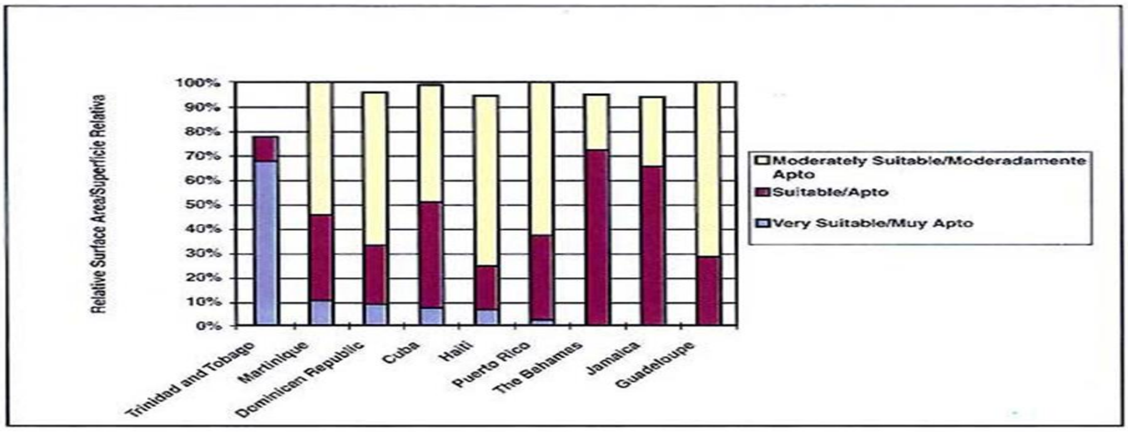

Figure 6 Spatial distribution (map) and relative area (histogram) of potential use of agricultural by-products as feed and fertilizer inputs (CRFM, 2014).

Table 4 Feed ingredients used in Kenya, Tanzania, and Rwanda and common price (in USD).

Ingredients	**Country**					
	Kenya		Rwanda		Tanzania	
	Occurrence	Cost US $/kg	Occurrence	Cost US $/kg	Occurrence	Cost US $/kg
Fish meal (*Rastrineobola argentea*)	√	0.76			√	0.4
Shrimp (*Caridina nilotica*) meal	√	0.5			√	0.4
Cow (*Bos taurus*) Blood meal	√	0	√	0.35	√	
Cow (*Bos taurus*) ofals			√	0.88		
Cow (*Bos taurus*) Bone Meal	√	0.63				
Cassava (*Manihot esculenta*) leaves	√	Na		Na	√	Na
Cassava (*Manihot esculenta*) flour					√	0.07
Premix	√				√	
Soya bean (*Glycine max*) flour	√	0.7				
Rice (*Oryza sativa*) bran	√	0.08		0.09		0.09
Rice (*Oryza sativa*) polishing	√	0.16				0
Maize (*Zea mays*) bran	√	0.25		0.44	√	0.14
Wheat (*Triticum aestivum*) bran	√	0.08		0.53		
Wheat (*Triticum aestivum)* pollard	√	0.15				
Maize (*Zea mays*) corn glutten	√	0.78				
Arrow root (*Maranta arundinacea*) leaves	√	Na	√	Na	√	Na
Sweet Potatoe (*Ipomoea batatus*) leaves	√	Na	√	Na	√	Na
Banana (*Musa paradisiaca*) leaves			√	Na		
Papaya (*Carica papaya*)	√	Na	√	Na	√	Na
Mchicha (*Amaranthus blitum*)	√	Na	√	Na	√	Na
Galant soldier (*Galinsoga parvilora*)	√	Na				
Avocado (*Persea americana*)	√	Na	√	Na	√	Na
Lucerne (*Chamaecytisus palmensis*)	√	Na	√	Na	√	Na
Sunlower (*Helianthus annuus*) seed cake	√	0.19			√	0.12
Peanut (*Arachis hypogaea*) cake			√	0.15		
Cotton (*Gossypium spp*) seed cake	√	0.23			√	1.72
Cabbage (*Brassica oleracea*)		Na	√	0.09	√	0.4
Concentrate			√	0.35		

Na = Not applicable; the feedstuff may be sourced off farm, off field or the household at no defined cost. Source: J. M. Munguti et al. (2012).

Table 5 Comparison of nutritive levels of selected common animal and plant feed ingredients of the current study in Kenya, Tanzania & Rwanda, and previous studies elsewhere in the world.

Product	*DM	CP	EE	CF	NfE	Ash
	g/kg	Gram per Kilogram of Dry Matter (g/kg DM)g/kg DM				
Fresh water shrimp (*Caridina nilotica*) meal						
Current study (Munguti, et al)	903	635	85	106	81	93
Kenya						
India	-	455	-	-	-	221
Madagascar	-	736	66	-	-	186
Malaysia	795	455	21	400	-	124
Maize (*Zea mays*) bran						
Current study	894	118	107	55	349	29
Tanzania	890	106	48	13	19	814
Thailand	880	109	50	34	29	768
Wheat (*Triticum aestivum*) bran						
Current study (Munguti, et al)	882	171	58	127	582	60
Tanzania	876	169	38	64	113	616
Malaysia	881	188	46	54	97	616
India	907	139	83	46	131	601
Rice (*Oryza sativa*) bran						
Current study (Munguti, et al)	923	70	41	309	349	229
India	913	137	54	181	488	181
Thailand	886	174	27	104	509	106
Malaysia	899	109	108	136	454	136
Arrow root (*Maranta arundinacea*) leaves						
Current study (Munguti, et al)		903	335	85	106	381
Banana (*Musa paradisiaca*) peel						
Current study (Munguti, et al)		901	72	79	113	627
Nigeria		141	79	-	-	-
Cotton (*Gossyium spp*) seed cake						
Current study (Munguti, et al)		892	388	107	249	192
Egypt		879	264	57	66	242
USA		989	461	7	71	151
Israel		923	477	54	66	125
Sunflower (*Helianthus annuus*) cake						
Current study (Munguti, et al)		929	259	54	368	266
Uganda		910	341	143	132	318
Rwanda		918	269	-	69	-
Nigeria		-	411	-	-	-
China		-	316	89	24	-
Cassava (*Manihot esculenta*) leaves						
Current study (Munguti, et al)		919	308	86	156	368
Nigeria		256	147		-	-
Papaya (*Carica papaya*) leaves						
Current study (Munguti, et al)		903	282	105	130	329
Nigeria		184	91	56	-	-

Sweet potato (*Ipomoea batatus*) leaves						
Current study (Munguti, et al)		892	353	43	105	388
Israel		892	194	37	259	105
Malaysia	913	188	23	113	188	488
Trinidad	877	219	34	150	180	417
Nigeria	946	28.55	-	-	-	475
Water fern (*Salvinia auriculata*)						
Current study (Munguti, et al)	888	232	49	302	239	179
India	-	116	28	204	469	183
Cotton (*Gossyium spp*) husks						
Current study (Munguti, et al)	878	638	12	179	51	120
Brewery by-product						
Current study (Munguti, et al)	-	455	-	-	-	221
India	291	243	52	196	451	58
Tilapia (*Oreochromis spp*) fillet remains						
Current study (Munguti, et al)	-	736	66	-	-	186
Catfish (*Clarias gariepinus*) fillet remains						
Current study (Munguti, et al)	795	455	21	400	-	124

DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fibre; NfE, N-free extract. Source: J. M. Munguti, et al. (2012).

The use of plant protein has become an urgent need over the past decade, as aquaculture nutritionists seek suitable replacements for animal protein. However, most plant protein sources lack one or more of the essential amino acids required for optimal growth and immune system function in tilapia (Kubitza, 2019; Montoya-Camacho et al., 2018). The use of by-products from plants and animals is a smart way to improve the sustainability of fish farming by reducing waste and creating value for otherwise unused by-products. This is important for attaining the United Nations SDG 14 goals for aquaculture and fisheries.

The development of circular economies is an important part of SDG 14 to alleviate poverty, create employment, provide food security and sustainably protect the environment. Ingredients from plant-based raw materials have become a significant part of the solution as we seek to sustainably meet the nutritional demands of aquaculture production, particularly tilapia. The use of plant protein as a partial replacement for animal protein has been successful in feeding many aquaculture species (El-Saidy and Gaber, 2003; Fasakin et al., 1999; Table 6). Plant protein is usually cheaper than animal protein, which could help reduce the cost of tilapia feed, making the industry more economically viable**.** However, plant protein is usually deficient in some essential amino acids (EAA), such as lysine and methionine, and must be carefully blended with feedstuff that will provide these vital nutrients. The use of plant-based feed ingredients will continue to increase as more research is conducted and discoveries are made and implemented.

Table 6 Approximate nutritional composition of plant-based ingredients used in tilapia feed.

Feeds of plant origin	Dry Matter (%)	Approximate Composition (%)			
		Crude Protein	Crude Fat	Crude Fibre	Ash
Barley, whole grain ground	92	11.5	1.9	5	2.5
Wheat bran	89	14.8	4	9.9	5.3
Wheat gluten meal	89	80.7	1.5	0.5	0.7
Wheat middlings	89	16.6	4	7.5	4.5
Brewer's dried grain	92	23.1	6.4	13.7	3.7
Rice bran	91	13	7.4	17.9	24.7
Corn grain meal	88	10.2	4.8	2.8	1.6
Corn gluten meal	91	63.7	2.2	1.5	1.6
Oats bran	90	11.2	5.4	10.6	2.6
Peas (shelled and extruded	90	25.3	1.4	6.9	3.3
Peanut meal(groundnut)solvent extracted	92	49	1.3	9.9	5.9
Conola (rapeseed) meal, solvent extracted	93	38	3.8	11.1	6.8
Conola (rapeseed) low erucic acid	89	32.9	3.2		
Cottonseed meal, solvent extracted	92	41.7	1.8	11.3	6.4
Coconut meal	93	22	6	12	7
Linseed meal (flax meal), solvent extract	90	35	1.6	8.9	5.7
lupin meal (sweet white	92	30.4	6.7	1.1	3.7
Molasses, cane, dried	94	9.6	0.8	6.2	12.5
Sesame meal, mechanically extracted	94	42	7	6.5	12
Soybean meal, solvent extracted,44% CP	89	44	1.5	7.3	6.3
Soybean seeds, extruded, full fat	90	35.2	18	5	4.5
Sorghum, milo, grain	89	9.9	2.8	2.3	1.8
Sunflower meal, solvent extracted	90	32.3	2.3	21	70
Yeast, brewers', dried	93	42.6	1	3.2	6.6

Source: NRC, 2011.

Jamaica is rich in natural resources, has a vibrant agriculture industry, food processing, and an excellent hospitality industry, and thus has several locally available raw materials that could be valuable in the formulation of tilapia fish feed. These include wheat bran, rice bran, brewery waste (grains), duckweed, moringa, molasses, poultry meal, feather meal, and lobster heads (

Table 7). These raw materials must be collected, properly stored, and processed for optimal use. Some of them, such as duckweed and moringa leaves, would need to be cultivated in large quantities, but this is possible due to Jamaica's excellent climate and the ability of these plants to multiply rapidly. There are good quantities of by-products from fish processing plants that are currently not being used, particularly from lobster and conch which could be processed into meals.

In 2021, Jamaica's poultry industry produced over 130,000 MT of poultry meat. Currently, neither of the two poultry-producing companies (Caribbean Broilers Ltd. and Jamaica Broilers Ltd.) is producing poultry or feather meal as byproducts of their operations. Ryco Jamaica Ltd., a local company, used to produce poultry meal from poultry by-products from Jamaica Broilers Ltd.; however, they stopped producing poultry meal in 2022. There is a great opportunity for Jamaica to produce these raw materials, thereby creating value in terms of employment, waste reduction, and increased productivity while being environmentally sustainable.

Table 7 Potential local sources of raw materials for tilapia feed in Jamaica.

Potential Feed Ingredients	**Primary Use**		
	Protein supplement	Energy supplement	Both
Animal Origin			
Fish offal (heads, tails, and entrails)	√		
Lobster heads	√		
Conch by-products	√		
Poultry Offal	√		
Poultry meal	√		
Fried regenerated oil		√	
Plant Origin			
Wheat middling			√
Cassava waste			√
Brewery spent grain (BSG)			√
Duckweed	√		
Cassava (Manihot esculenta) leaves			√
Sweet Potatoe (Ipomoea batatus) leaves			√
Banana (Musa paradisiaca) leaves			√
Avocado (Persea americana)		√	
Peanut (Arachis hypogaea) grain			√
Molasses		√	
Cabbage (Brassica oleracea)		√	
Brewery spent yeast (BSY)			√
Coconut meal		√	
Plant and Animal Origin			
Kitchen, Restaurant, and bakery wastes			√

Primary Source: NFA, 2022.

Best Dress Mills is the only company producing commercial feed in Jamaica. Their 9006-2 Tilapia 28 Super 10 feed is a sinking pellet and is not suitable for all stages of the production cycle of tilapia. One farmer has been producing feed for his fish using local raw materials; however, this feed is not made according to any nutritional standard, and it is also a sinking pellet. Two of the largest farms in Jamaica (Longville Fish Farm and Dencon Farm) have been importing feed to meet the feed demand of their farms and the nutritional needs of their fish at different stages of the production cycle.

Feed has been imported from the USA, Norway, and Costa Rica by the following companies: South Fresh Feeds, Zeigler, Skretting, and BioMar. All imported feeds are floating pellets and contain either 60%, 42%, 36%, or 32% protein. Based on data obtained from tilapia farmers, they imported approximately 696 MT of feed in 2021, with an estimated value of USD 311,500 (

Table 8). Based on data from the Jamaica Customs Agency, approximately 1,013 MT of tilapia feed was imported in 2022 at an estimated value of USD 1,098,560. Data collected by the NFA show that approximately 3.76 MT of Zeigler (4,000/MT), 550 MT of South Fresh Feeds (610/MT), and 459.24 MT of Biomar feeds (1,480/MT) were imported in 2022. There was an 8.11%, 52.5%, and 106% increase in price, respectively, between 2021 and 2022 (Table 9).

Table 8 Imported tilapia feed and estimated value in Jamaica 2021. Source: NFA, 2022.

Farm/Organization	Feed Company name	Quantity (tons)	Cost (USD/Ton)
Longville Fish Farm	South Fresh Feeds	130	400
	Skretting	50	600
(Via RERUM)	BioMar	33	800
Dencon Farms	South Fresh Feeds	480	400
	Zeigler	3	3,700
	Total	**696 MT**	**USD $311, 500**

Table 9 Price of tilapia feeds in 2021 and 2022

Feed Source	Cost/Ton (USD)/ year		Increase (%)
	2021	2022	
South Fresh Feeds (Imported)	400	610	52.5
Skretting (Imported)	600	0	N/A
BioMar (Imported)	800	1,648	106
Zeigler (Imported)	3700	4,000	8.11
Best Dress Feed Mills (Local)	760	852	12.1

Prices for imported feed do not include mark-up by the importer. Source: NFA, 2022; Author´s calculations.

4.2 Nutritional profile of tilapia feeds

The nutritional requirements of tilapia have been widely researched to determine the optimal diet for the productivity and health of farmed fish (do Nascimento et al., 2020; Kubitza, 2019; Munguti et al., 2006). There are different nutritional requirements at different stages of development; however, in general, feeds contain the basic nutrients, such as protein, fat, carbohydrates, vitamins, and minerals (NRC, 2011).

The National Research Council's nutritional recommendations for fish have been used as a standard by most fish nutritionists. The protein requirement in the form of essential amino acids (EAA) is a vital part of the diet (Table 10). A lot of emphasis has been placed on the stage of development in the production cycle and the digestibility of the diet to optimise productivity (

Table 11). Tilapia feed manufacturers have been producing feed accordingly, resulting in improved feed conversion ratios (FCR) and productivity.

Table 10 Quantitative essential amino acid requirements (percent of dietary protein) for Nile Tilapia. Source: NRC, 2011.

Amino Acid	**Requirement %**
Arginine	1.2
Histidine	1
Isoleucine	1
Leucine	1.9
Lysine	1.6
Methionine	0.7
Met+Cys	1
Phenylalanine%	1.1
Phe+Tyr	1.6
Threonine	1.1
Tryptophan	0.3
Valine	1.5

Table 11 Feed formulae (ingredient composition) and approximate composition of commonly used farm-made feeds (as fed basis) for different life stages of Nile tilapia in semi-intensive farming systems in Thailand. Source: Thongrod (2007).

Ingredient/proximate composition	**Life stages/size class**			
Ingredient composition (%)	Early fry	Fingerling	Grower (in cage)	Grower (in pond)
Cassava starch	15	0	0	0
Cassava meal	0	23	23	22
Coconut meal	0	0	0	30
Rice bran	30	15	20	0
Soybean meal	0	30	25	25
Fish meal	47	25	25	20
Fish oil	5	4	4	0
Dicalcium phosphate	1	1	1	1
Vitamin and mineral premix*	2	2	2	2
Proximate composition (%)				
Dry matter	8.3	9	9	9.1
Crude protein	30	31	30	29.9
Crude lipid	10	7.4	7.5	4.1
Ash	16.3	12.6	12.8	10.7
Crude fibre	3.8	4.2	4.4	6
NFE	31.6	35.8	36.3	40.2
Gross energy (kcal/kg feed	2,800	2,700	2,700	2,500
Cost (Baht/kg)	15.1	11.3	10.7	8.5
Cost (US$/kg)	0.45	0.34	0.32	0.26

4.3 Nutritional profile of potentially available raw materials

The potentially available raw materials in Jamaica have been used as raw materials for feed in other parts of the world, especially in Africa and Asia. The nutritional profiles of these ingredients provide vital data for feed formulation. A wide variety of feedstuffs are used as supplemental feed ingredients worldwide (Table 12). Some feedstuffs are not available locally; however, there is sufficient data available to assist with the formulation of suitable diets for tilapia. These raw materials have been used with some level of success, especially in Africa and Asia, where they have similar challenges and climatic conditions to Jamaica.

Table 12 Nutritional profile of the most used supplemental feed ingredients in tilapia aquaculture.

Feed ingredients	**Nutrient composition**				**Gross energy (kJ/g)**	**Estimated FCR**
	Moisture	**Crude protein**	**Crude lipid**	**Ash**		
Feeds of animal origin						
Blood meal	10.4	81.5		2	20	1.5 - 1.7
Chironomids, fresh	84	9	14	7	7.5	2.3 - 4.4
Daphnids, fresh	89-94	3 - 7.5			1.2 - 2.5	4 - 6.4
Earthworm, fresh	3.0 – 21	10.6	1.0 - 2	1.0 - 3	3.1	8.0 – 10
Fishmeal	8.0 – 9	57 - 72.7	4.0 - 9	10.0 - 26	16.8 - 20.7	1.5 - 3.0
Liver, spleen	70 – 73	20.2 - 20.5			6.7 - 7.3	5.5 - 8.0
Locust, dried	10.5	46.2			20.5	5
Locust, fresh	68.2	1.0 - 22			7.1	1.0 – 10
Trash fish, raw	52-83	11.0 - 26	1.0 - 36	1.0 - 2		4.0 – 9
Meat meal	6.9	53		1.0 - 31	16.8	1.0 – 2
Poultry viscera, fresh	74	14	11	1		5.0 – 8
Silkworm pupae, dried	10	55.9		1.9	24.2	1.3 - 2.1
Silkworm pupae, fresh	74.9	13.7	8	1.2	6.9	3.0 – 5
Snail meat, dried	5.7	62.7			20.6	10.2
Snail meat, fresh	78	12	1	4	4	22
Feeds of plant origin						
Banana leaves	75	2.4	1		4.7	25
Cassava leaves	74.4	7.7	1	2	4.9	10.0 – 20
Corn	12.2	9.6	4	2	16.3	4.0 – 6
Cottonseed cake	7.8 - 10.7	21.9 - 41.2		8.3	16.9 - 18.7	3
Ground rice	11.3	7.5	0.6	0.6	15.8	4.5
Groundnut cake	9.6 – 10	30.2 - 46.2	9	8.6	6.7 - 9.1	2.0 – 4
Palm oil cake	10.5	17.7	10	3.3	18	6.0 – 12
Rye grass	88.3	2.9			15.1	17 – 23
Soybean	8.8 - 9.1	24.1 - 37.8	10	7	18.3 - 21.2	3.0 – 5
Water hyacinth	91.5	1.2	0.3	1	1.4	50
Wheat bran	12.1	14.7	4	5.5	16	6.1 - 7.3
Wheat flour	12	11.7	1	0.5	16.1	7.2

Data source: Tacon (1987; 1988)

4.4 Feed formulations used worldwide

Fish feed is manufactured based on the needs of the fish and the desired outcome of the production cycle. Some basic factors to consider are as follows:

1. Nutrient requirements of the species cultivated.
2. The feeding habit of the species
3. Ability of the cultured organism to utilise nutrients from various ingredients as well as the prepared diet.
4. Nutrient composition of the ingredients (macro-and micronutrients).
5. Digestibility energy (DE) and metabolisable energy (ME) of the ingredients.

6. Flavour quality and palatability
7. Local availability and cost of the ingredients.
8. Expected feed consumption (FCR).
9. Feed additives needed.
10. Type of feed processed (sinking or floating feed).

Generally, feeds are formulated according to the life stage of the fish (Table 13). Feeds are also manufactured based on the environments in which they are used. The feed must be able to maintain its nutritional value under different conditions, such as seawater, brackish water, fresh water, ponds, or cages. The main objective of feed formulation is to provide a balanced diet at the lowest cost. This means that all feedstuffs of different nutritional qualities must be mixed in the correct proportions to provide a balanced diet and meet the nutritional needs of the fish. Protein is an essential component of this diet, and tilapia feed should contain between 28% and 45% protein for reasonable growth, good health, and to attain a good digestible energy/crude protein (DE/CP) ratio (Kubitza, 2019).

Table 13 Composition of commonly used ingredients and approximate nutritional composition of pelleted feed for different life stages of Nile Tilapia

Ingredient Composition (%)	**Pre-starter**	**Starter**	**Grower**	**Finisher**
Fish Meal	15	12	10	5
Fish oil	4	3	3	2
Corn	0	0	3.1	14.9
Rice bran	0	24.6	35	35
Wheat bran	10	10	10	10
Cassava	6.7	10	10	10
Soybean meal	62.4	38.5	27.3	21.1
Limestone	0.6	0.7	0.7	0.8
Dicalcium phosphate	1.1	1	0.7	1
Vitamin premix	0.1	0.1	0.1	0.1
Mineral premix	0.1	0.1	0.1	0.1
Approximate Composition (%)				
Crude Protein	40	30	25	20
Crude lipid	6	5	4	4
Crude fibre	3.5	4.7	5.2	5.5

Source: Creswell (2005)

4.5 Possible tilapia feed formulations that could be used locally.

Jamaica has an excellent opportunity to use locally available raw materials for tilapia fish feed. The identified locally available raw materials have a fair to excellent nutritional profile and are available in sufficient quantities (Tables 12 and 13). The crude protein (CP) content of tilapia diets is vital, and some local raw materials have a good protein profile. The current feed produced by Best Dressed Feed Mill is 9006-2 Tilapia 28 Super 10. The label on the feed bag states that the feed has the following ingredients: soybean meal, ground yellow corn, processed grain by-product, fish meal, mono-calcium phosphate, molasses, amino acids, fat preserved with antioxidant, sodium chloride (salt), vitamin A, C, D, E, K, biotin, choline, folic acid, inositol, niacin, pantothenic (B3), riboflavin (B2), thiamine (B1), pyridoxine (B6), cobalamin (B12), traces of cobalt, iron, copper, iodine, magnesium, manganese, sodium, sulphur, zinc, selenium, potassium, and chromium. The label also states that the feed has the following nutritional composition: 28% protein, 4.4% fat, 4.2% crude fiber, 88.5% dry matter. All these ingredients are imported, except for molasses and sodium chloride (salt). Minimising the use of imported raw materials is one of the goals of this study, to reduce the cost and improve the sustainability of feed production. The use of mostly or all local feedstuff would be expected to significantly reduce the price of feed locally. Vitamin and mineral premixes are the most necessary imported ingredients. However, these can be produced locally in the future.

The Diet Formulator Programme (adapted from Professor Ólafur Sigurgeirsson, Department of Aquaculture and Fish Biology, Hólar University) was used to formulate a potential fish feed from previously identified locally available raw materials. Several potential formulations can be used based on fish diets that are currently being used successfully worldwide (FAO, 2023; do Nascimento et al., 2020; Kubitza, 2019; Munguti et al., 2006). However, the formulations would depend on Jamaica´s ability to source materials and prepare feed pellets. The diet presented here (Table 14 and Table 15) meets the minimum essential amino acid (EAA) requirement and has a very good protein percentage. This shows that there is great potential to develop excellent-quality feed locally, Figure 7.

Table 14 Possible composition of Tilapia feed made from local raw materials

Ingredients	**Percent %**
Fish offal meal	10
Lobster heads meal	6
Conch by-products meal	5
Poultry meal	32
Wheat mill run	20
Distillers/brewers grain	14
Peanut seed	3
Casava leaves meal	2
Fish oil	2
Limestone	0.6
Vitamin premix	0.1
Brewery spent yeast (BSY)	5
Salt	0.3
Total	100

Table 15 Estimated nutritional profile of the proposed locally formulated diet.

DM%	91.38
Ash%	10.99
GE MJ/kg	19.60
DE MJ/kg	13.02
CP%	41.95
Dig CP%	35.26
Lipid%	11.39
Fibre %	5.90
LOA (18:2n-6) %	1.10
LNA (18:3n-3) %	0.12
ARA (20:4n-6) %	0.04
EPA (20:5n-3) %	0.27
DHA (22:6n-3) %	0.41
Total n-3 %	0.79
Total n-6 %	1.14
n3: n6	0.70
Total phospholipid %	2.56
Cholesterol %	0.19
Astaxanthin (mg/kg)	1.65
Arginine %	2.71
Histidine %	0.79
Isoleucine %	1.63
Leucine %	2.78
Lysine %	2.43
Methionine %	0.61
M+C %	1.39
Phenylalanine %	1.64
P+T %	2.95
Threonine %	1.63
Tryptophan %	0.42
Valine %	1.87
Ca %	2.41
Available P%	1.07
Cost/kg	USD$851

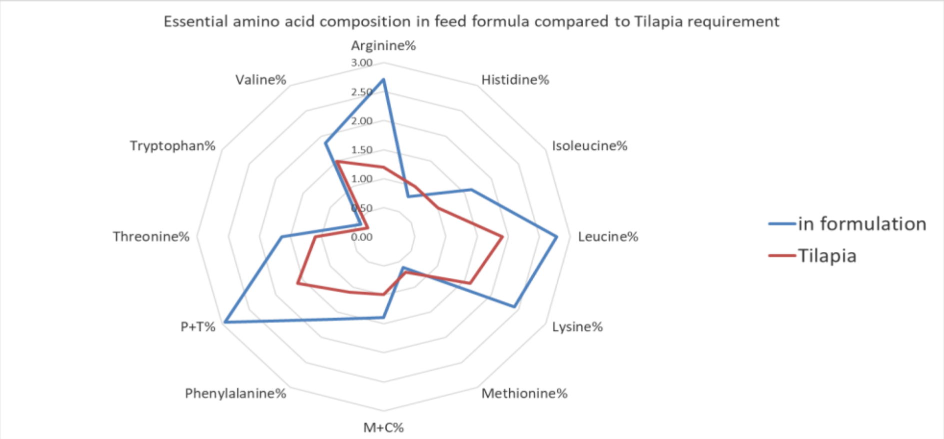

Figure 7 Comparison of essential amino acids in the presented formulated diet to Tilapia requirements. The feed formulation and nutritional information were calculated using the Diet Formulator software.

4.6 Fish feed price comparisons

The cost of local feed has increased dramatically over the past few years. Since 2021, the price of local feed (Hi-Pro Feeds, Tilapia Super 10) has increased from an average of USD 0.76 per kg to the current price (as of March 2023) of USD 0.90 per kg, representing an 18.42% increase in price. The price of feed usually increases each time a new batch of feed is manufactured because of the escalating prices of almost exclusively imported ingredients. The interviewed farmer who produced homemade feed using locally available feedstuffs claimed that his production cost was approximately USD 20 cent/kg in 2021. However, the quality of homemade feed is poor, resulting in longer crop cycles.

In 2022, Jamaica continued to import feed from BioMar Aqua Corporation Products, Costa Rica. Four types of feed were imported, containing 60%, 42%, 36%, and 32 % protein. One of the largest farmers (Longville Fish Farm) reported that the feed conversion ratio (FCR) decreased from approximately 2.5 to 1.1 over the last two production cycles using only BioMar feeds. The price of BioMar feed was approximately USD 3.60 (for 60%), 2.62 (for 42%), 1.76 (for 36%), and 1.58 (32%) per kg. The reduction in FCR from 2.5 for local feed to 1.1–1.6 for imported feed could compensate for the increase in feed cost.

Calculating the accurate cost of a hypothetical feed produced from local raw materials is difficult; however, the current cost of some raw materials was used to estimate the feed price (Table 16). Operational costs, such as raw material collection, preparation and processing, transportation, and storage, must also be considered. Capital costs, such as those associated with equipment and storage facilities, are also important.

There are two industrial flour mills, Jamaica Grain and Jamaica Flour Mills Limited (JFM), which produce and sell grain middling by-products at USD 217,10/MT to the animal feed industry. The amount produced was not available but was estimated to be sufficient for industrial feed production. The Heineken beer factory produces approximately 3,500 MT of spent grain by-products, which have previously been sold to beef producers at USD 9.87/ton, approximately 540 tons of spent yeast (in pasty form, with approximately 20% dry matter), and cassava waste, which is currently discharged as waste. A vast amount of waste from kitchens, markets, restaurants, hotels, and bakeries can also be considered for use as raw materials. Waste from markets and bakeries has been successfully used as an ingredient in tilapia feed (Al-Ruqaie, 2007).

Caribbean Broiler Group, the second-largest producer of chicken meat in Jamaica, has just completed the construction of a new processing plant, and they indicate that they will be producing poultry offal meal. They also own the Nutramix Feed Mills, which produces animal feed for several livestock, except for fish. Table 17 attempts to estimate the cost per metric ton (MT) of the locally produced diet formulation. The current costs of some raw materials are available (wheat bran, poultry offal meal, fish meal, and brewery offal). The prices of other ingredients were estimated based on the local economy.

Table 16 Estimated availability, cost, and protein content of locally available fish feed materials in Jamaica. Source: NFA, 2022.

Source of Raw Material	Availability (Mt)	Cost/Mt (USD)	Protein Content %	Moisture Content %
Wheat mill run	55000	215	12	11
Fish by products (fish meal)	2000	1300	70	11
Rainforest Caribbean fish+meat waste	70	1200	65	12
Poultry offal meal	>5000	900	60	11
Chicken and pig rendering (Nutra Mix)		160	60	11
Molasses feed grade		220		27
Brewery spent grain (BSG)	3500	12	15	75
Brewery spent yeast (BSY)	540	100	45-60	80
Casava flour (Casava waste)		12	12	4
Casava leaves meal		220	28	4
Duck weed (dry plant)		220	25 -35	92
Peanut seed		2000	25	4
Limestone		645		

Note: Prices are estimated based on the current local situation.

Table 17 Estimated cost per metric ton (MT) of a diet prepared from mostly local raw materials

Ingredients	Percent (%) in kg	Cost/ton (USD)
Fish offal meal	100	130
Lobster heads meal	60	90
Conch by-products meal	50	75
Poultry meal	320	288
Wheat mill run	200	43
Distillers/brewers grain	140	1.2
Peanut seed	30	60
Casava leaves meal	20	4.4
Fish oil	20	20
Limestone	6	3.87
Vitamin premix	1	24
Brewery spent yeast (BSY)	50	5
Salt	3	2.13
Labour		48
Electricity		6.15
Miscellaneous		50
Total	**1000**	**850.75**

Note: All local ingredients except fish oil and vitamin premix which are 2.1% of diet.

The estimated cost of this diet shows that it is possible to produce high-quality local fish feed that meets or exceeds the nutritional requirements for aquaculture tilapia. The cost of one metric ton of Hi-Pro Feeds Tilapia Super 10 was approximately USD 752 in 2021, and this is a sinking pellet with only 28% of protein. The cost per ton in 2022 was approximately USD 852, representing a 12.1% increase in one year. The diet formulated from locally available materials (Tables 14 and 15) contained approximately 42% protein, with 35% digestible crude protein (Dig. CP) and costs approximately USD 851/ MT.

When we compare the cost of local, imported, and formulated feeds based on prices in 2022, the locally formulated feed would be the cheapest (Figure 8). However, this is an estimate, and the price of local feed may be higher. Special attention is placed on the protein content of feeds because it is the most essential and expensive part of the fish diet. Based on the potential volume of raw materials available, locally produced fish feed is believed to have good potential as a profitable and suitable enterprise (Figure 9).

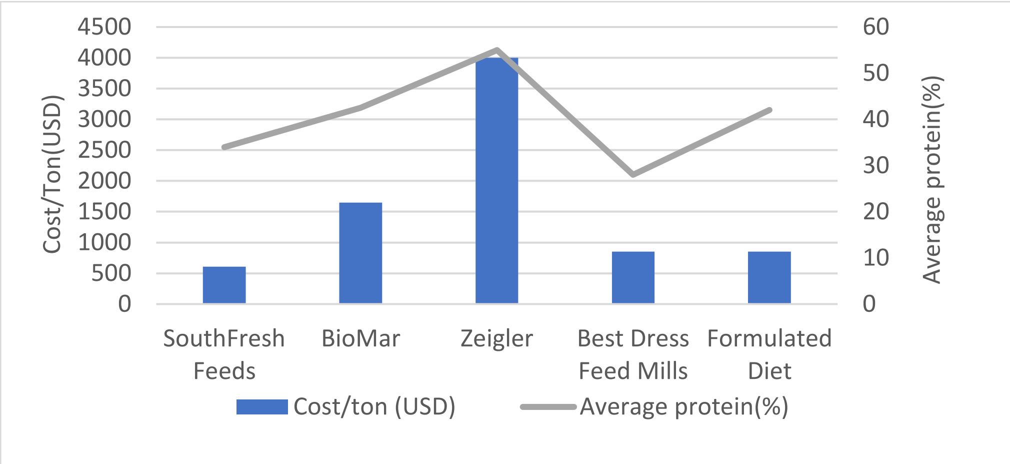

Figure 8 Comparison of cost per ton and average protein content of tilapia feed in Jamaica in 2022 (NFA, 2022).

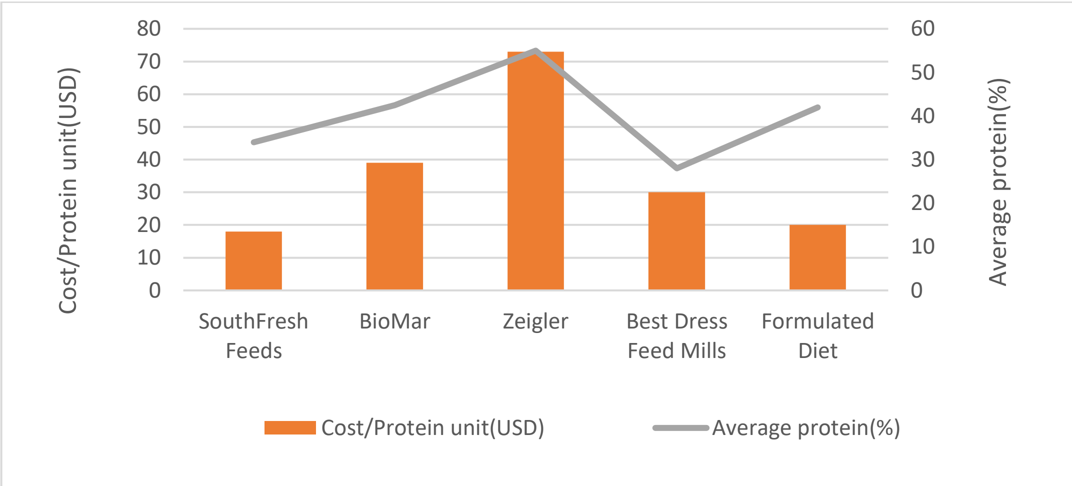

Figure 9 Comparison of estimated cost per unit of protein in local, imported, and formulated feed.

To evaluate the cost-effectiveness of imported feeds versus locally produced feed, the costs and returns on four (4) half-hectare (0.5) ponds stocked with 10,000 tilapia fingerlings each per crop cycle were estimated (Table 18). The calculations were for one year of production using 20% mortality, considering the cost per ton of feed, feed conversion ratio (FCR), crop cycle, cost per protein unit, estimated harvest/year, and current price of tilapia. Based on these estimates, imported feeds and formulated local diets were more profitable than locally produced feeds (Best Dress), with net returns of USD 16,360 (South Fresh feeds), USD 14,240 (BioMar feeds), USD 8,337 (Best Dress feed), and USD 17,119 (formulated local diet) per year. This was primarily due to a lower FCR for the imported feeds and formulated diet, resulting in shorter crop cycles and improved profit margins from the ponds.

Table 18 Estimated comparison of cost effectiveness of imported feeds, locally manufactured feed, and the potential formulated local diet.

Data Source	SouthFresh Feeds	BioMar Feeds	Best Dress Feed Mills	Formulated Diet
Cost/Ton (USD)	610	1648	852	851
Estimated FCR.	2	1.4	2.8	1.8
Production cycle (months)	7	5	8	6
Crop/Year	1.5	2	1.25	1.75
Average protein (%)	34	42.5	28	42
Cost/Protein unit (USD)	18	39	30	20
Estimate feed/Crop (MT)	7.3	5	10.2	6.5
Estimated Harvest/Year (Kg)	3600	4800	3000	4200
Feed Cost per Kg	1.85	3.43	3.62	2.3
Cost/year (USD)	6680	16480	10863	9681
Gross Return/Year (USD)	23040	30720	19200	26880
Profit/loss (USD)	**16360**	**14240**	**8337**	**17199**

5 FEASIBILITY OF FEED PRODUCTION IN JAMAICA

Two commercial feed manufacturers currently produce a wide range of animal feeds. However, as stated before, only one company produces tilapia fish feed. The feed is a sinking pellet and is therefore not suitable for all stages of the production cycle. When manufacturing feed for fish, certain parameters must be considered, such as pellet size, uniformity, texture, density, storage, handling, and nutritional content. Floating pellets are more suitable for tilapia production (Bouvier & Brisset, 2006). Currently, there is no extrusion feed manufacturing machine in Jamaica, and this could be a significant part of the solution to improve productivity in the medium to long term.

Feed extrusion machines produce feeds of different sizes and textures (both floating and sinking) which is vital for the different stages of production. These machines operate in a particular sequence to ensure feed quality (Figure 10). They are expensive, and there is currently no extrusion machine in Jamaica. Acquiring this machinery would be a significant step in improving productivity, and this is where the formation of fish farmer cooperatives could be beneficial. This is the practice in most developed and developing countries involved in tilapia production.

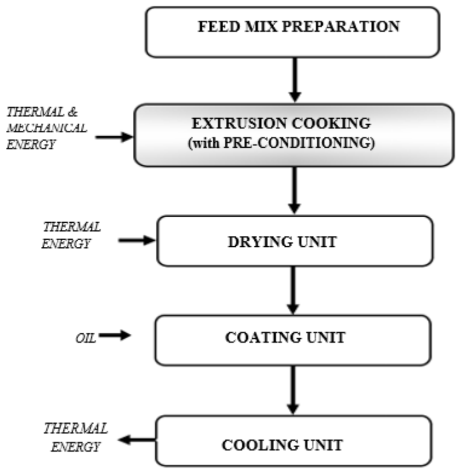

Figure 10 Diagram of aquafeed extrusion processing.

Extrusion machines are expensive and require significant capital investments (Figure 11). However, they are long-term investments that are cost-effective if managed properly. Both governments and farmers have a vested interest in increasing aquaculture subsector productivity. These machines can also be used to make feed for other species of farmed fish, such as shrimp, catfish, and carp (Figure 12). The acquisition of feed extrusion machines should be economical, as this is a capital investment which is expected to be useful for a long time. The cost of a high-quality floating fish feed production machine is between USD 130,000 and 190,000. Companies that sell these machines usually assemble and service them.

Figure 11 Floating fish feed extruder machine (https://www. zenopelletmachine).

Figure 12 Samples of extruded fish feed pellets of various sizes (Havsbrún Feed Factory, Faroe Islands).

5.1 Attitude of current and prospective feed manufacturers towards using the identified raw materials and technology.

Dialogs with the current local feed producer in Jamaica (Best Dressed Feed Mills) suggest that they are willing to use local materials, particularly poultry meal. However, they have not shown any interest in producing poultry meals themselves. Nutra-mix Feed Mills, another local feed manufacturer, indicated that they are considering the possibility of producing fish feed. Their parent company, Caribbean Broilers, indicated that they would produce poultry meals at their new processing plant in St. Catherine. This plant is located approximately 5 km from Hill-run, the largest tilapia farming community in Jamaica. It is hoped that this poultry meal will be used to make fish feed. Farmers who make homemade feed are willing to learn and cooperate with the idea of making local feed.

It is estimated that Jamaica will be able to start producing extruded tilapia feed from local raw materials in two years. The acquisition and installation of the extruder machine will take about six months, and the training of staff to operate the machine should take about three (3) months.

6 CONCLUSION AND RECOMMENDATIONS

The use of local raw materials as fish feed ingredients appears to be a great opportunity for Jamaica to improve the economic efficiency and sustainability of local fish-farming operations. However, much work would have to be done by both the government and the private sector. The government will need to implement policies that would facilitate local production, and the private sector will have to invest in equipment and personnel. The removal of taxes on agricultural equipment would help facilitate the acquisition of extruder technology and other inputs.

The SWOT analysis of the proposed plan identified the following:

Strengths

- Suitable quantity and quality local raw materials
- The cost of the available raw materials is relatively low.
- Basic infrastructure is available to manufacture tilapia feed at two feed factories in Jamaica
- Strong market demand for Tilapia and attractive price for producers

Weaknesses

- The local feed is poor quality and expensive. There have been issues with feed availability
- Very poor-quality homemade feeds. Feed not made according to any nutritional standard
- The only two companies that produce feed do not have the extruder that would allow for higher feed quality.
- There are no specific financial instruments for domestic feed purchase and feed import logistics, and, in general, there is a lack of financial products dedicated to aquaculture**.**
- Most feed ingredients are imported, and only middlings and molasses are produced locally. Imports are taxed at 20% for both feed and feed components.

Opportunity

- High volume of potential raw materials (agriculture, food processing, and service industries).
- Based on estimates, the cost of producing feed is cost-effective and sustainable.
- Potential for large- and small-scale production (cooperative).
- The production of this feed is expected to create new business opportunities, employment, value, reduce waste, and protect the environment.

Threats

- Cost of collecting and preparing raw materials.
- Cost of acquiring and installing feed extruder technology.
- Lack of support from the government and private sectors.

There is a need for greater collaboration between the government, private sector, and research institutions. For example, on a recent visit to the Faroe Islands, it was observed that the government had policies in place to facilitate aquaculture production, and the private sector was abiding by these policies while using all the available information from research institutions to improve their operations. Aquaculture production companies are willing to share information with both the government and research institutions and facilitate research at their facilities.

This study recommends that immediate steps be taken to initiate the production of tilapia feed using local raw materials. Thus, taking an opportunity and making it a strength, while mitigating the threats that currently face the fish farming industry, as we seek to improve and increase the productivity of the local aquaculture sub-sector. The ultimate result would be the creation of employment, poverty alleviation, improved food security, and GDP.

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REFERENCES

FAO, 2023. Aquaculture Feed and Fertiliser Resources Information System. Retrieved from https://www.fao.org/fishery/affris/species-profiles/nile-tilapia/feed-formulation/en/. March 2023.

FAO, 2023. Fishery and Aquaculture Country Profiles. Belize, 2018. Country Profile Fact Sheets. Fisheries and Aquaculture Division [online]. Rome. Updated Jul 16, 2019.

FAO, 2022. The State of World Fisheries and Aquaculture (SOFIA) 2022.

NFA, 2022. Consultancy to Assess Local Availability of Fish Feed and Prepare a Strategy and Action Plan for Improving Accessibility to Affordable Quality Fish Feed. RFP No.: JM-MICAF-36542-CS-CQS. Alveo Soc.Coop. a r.l. - Via Bentivogli 4, 40055 Castenaso (BO), Italy.

NFA, (2022). Data Management Unit, Jamaica.

Worldbank, 2022. Aquaculture production (metric tons) - Latin America & Caribbean Data (worldbank.org)

Wurmann, C. Soto, D., Norambuena, R. 2022. Regional review on status and trends in aquaculture development in Latin America and the Caribbean – 2020. FAO Fisheries and Aquaculture Circular No.1232/3. Rome, FAO. https://doi.org/10.4060/cb7811en

NFA, 2022. National Fisheries Authority (NFA), Jamaica. 2020/2021. Survey & Data collection.

FAO, 2022. Jamaica. Text by DeHaan D. D. Brown. Fisheries and Aquaculture Division [online]. Rome.

Babatunde, A., Deborah, R.-A., Gan, M., & Simon, T, 2021. A quantitative SWOT analysis of key aquaculture players in Africa. Aquaculture International, 29(4), 1753–1770. https://doi.org/10.1007/s10499-021-00715-4

Caribbean Natural Resources Institute (CANARI). 2020. Institutional analysis of enabling conditions for ecosystem stewardship in the fisheries sector of Jamaica. Barataria, Trinidad.

do Nascimento, Thiago M.T., Mansano, C.F.M., Peres, H., Rodrigues, F.H.F., Khan, K.U., Romaneli, R.S., Sakomura, N.K., & Fernandes, J.B.K. (2020). Determination of the optimum dietary essential amino acid profile for growing phase of Nile tilapia by deletion method. *Aquaculture*, 523.

Kubitza, 2019. Advances in tilapia nutrition, part 1 « Global Aquaculture Advocate.

Kubitza, 2019. Advances in tilapia nutrition, part 2 « Global Aquaculture Advocate.

CRFM, 2014. Study on the Potential of Fish Farming in the Caribbean. CRFM Technical & Advisory Document No 2014 / 2. P78

Munguti, J., Charo-Karisa, H., Opiyo, M.A; Liti, D; Marijani, E. and Nzayisenga, L.(2012). Commonly utilized feed ingredients for culture of Nile tilapia (Oreochromis niloticus L.) and African catish (Clarias gariepinus Burchell) in Kenya, Tanzania and Rwanda.

Tacon, A.G.J.; Hasan, M.R.; Metian, M. (2011). Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects. FAO Fisheries and Aquaculture Technical Paper No. 564. FAO, 2011. 87 pp.

NRC, 2011. Nutrient requirement of fish and shrimp/Committee on the Nutrient Requirements of Fish and Shrimp, Board on Agriculture and Natural Resources, Division on Earth and Life Studies, National Research Council of the National Academics. National Academic Press, 500 Fifth Street, N. W; Lockbox 285, Washington, DC 20055. Pages 76-85; 258-266; 335-336.

Wurmann, Carlos. (2011). Plan for Aquaculture Development in Jamaica 2012 - 2025, prepared for Government of Jamaica.

Al – Ruqaie, I.M. 2007. Extruded leftover food as animal feed. Effect of extruded feeds on growth and feed utilization of Tilapia *Oreochromis niloticus* in Saudi Arabia. *Pakist. J. Biol. Sci*. 2007; **10** (**19**): 3248-3253.

Thongrod, S**.** 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Thailand. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and Analysis of Feeds and Fertilizers for Sustainable Aquaculture Development.* pp. 309-330. FAO Fisheries Technical Paper. No. 497. Rome, FAO. 510 pp.

Chang, H. and Huang, W. (2006) Application of a Quantification SWOT Analytical Method. Mathematical and Computer Modeling, 43, 158-169.

J. M. Munguti, D. M. Liti, H. Waidbacher, M. Straif and W. Zollitsch. (2006) Proximate composition of selected potential feedstuffs for Nile tilapia (Oreochromis niloticus Linnaeus) production in Kenya.

El-Sayed, A-F. M**.** 2006. Tilapia Culture. Oxfordshire, CABI Publishing. 277 pp.

Creswell, D. 2005. The feeding and nutrition of the tilapia. AQUA Culture Asia Pacific magazine, November/December, pp. 32-33.

Bouvier, J.M. & Brisset, A**.** 2006. Aquafeed twin screw extrusion processing. pp. 76-104. *Asian Aquafeeds: Current Developments in the Aquaculture Feed Industry*. Malaysian Fisheries Society Occasional Publication No. 13, Kuala Lumpur, Malaysia.

Koprucu, K. and Ozdemir, Y. 2005. Apparent digestibility of selected feed ingredients for Nile tilapia (Oreochromis niloticus). Aquaculture 250, 308-316.

Hanley, F. 2005. A guide to the farming of tilapia. Jamaica Boilers Group of Companies. Kingston, Jamaica.

El-Saidy, D.M.S.D and Gaber, M.M.A. 2003. Replacement of fish meal with a mixture of different plant protein sources in juvenile Nile tilapia *Oreochromis niloticus* (L.) diet.

Aquaculture Research 34(13):1119-1127.

Aiken, K.A. et al. 2002. Aquaculture in Jamaica, Naga, World Fish Centre Quarterly (Vol. 25, Nos. 3 and 4). July – Dec. 2002.

Fasakin EA, Balogum AM and BE Fasuru, 1999**.** Use of duckweed, (*Spirodela polyrrhiya,* L.) Schleiden, as a protein feedstuff in practical diets for tilapia (*Oreochromis niloticus*, L.). *Aquac. Res*. 1999; **30**: 333 –318

FAO, 1998. A Strategic Assessment of the Potential for Freshwater Fish Farming in Latin America (Kapetsky and Nath, 1997).

Tacon, A.G.J. 1988. The Nutrition and Feeding of Farmed Fish and Shrimp- A Training Manual. 3. Feeding Methods. FAO Field Document No. 7, Brazil, 208 pp.

Tacon, A.G.J. 1987a. The Nutrition and Feeding of Farmed Fish and Shrimp – A Training Manual. 1. The Essential Nutrients. FAO Field Document No. 2, Brazil, 117 pp.

Tacon, A.G.J. 1987b. The Nutrition and Feeding of Farmed Fish and Shrimp – A Training Manual. 2. Nutrient Sources and Composition. FAO Field Document No. 5, Brazil, 129 pp.