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Assessing the Potential of Locally Sourced Materials in The Formulation of Nile Tilapia Aquafeed in the Bahamas

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Abstract

Aquaculture has been identified for its role in addressing key United Nations sustainable development goals, primarily zero hunger, and responsible production and consumption. With an annual growth rate of 8.8%, aquaculture is the fastest-growing food sector globally, yet production in the Caribbean region has declined by 40% over the last two decades. This can be attributed to various factors including access to resources necessary for production, such as aquafeed. Most Caribbean islands rely on the importation of aquafeed from the US and Latin American countries, and when feed is produced in the Caribbean region, the main ingredients are imported. In this review, the use of locally sourced ingredients was explored for their potential in aquafeed formulation to produce comparable, if not superior diets for Nile tilapia (Oreochromis niloticus) and other tropical species. Various ingredients such as fly larvae (Hermetia ilucens; Musca domestica), moringa (Moringa oleifera), banana (Musa sp.), cassava (Manihot esculenta),) sweet potato (Ipomoea batatas), and guinea corn (Sorghum vulgare) were assessed for their viability as ingredients for formulating pelletized aquafeeds. Additionally, brewery industry and artisanal fisheries discards (e.g., spent grain, fin fish, spiny lobsters, conch) were identified as having the potential to be viable aquafeed inputs. The study concluded that based on availability and quality, complete aquafeeds can be formulated by substituting all the conventional ingredients with locally sourced raw materials. Most of the ingredients are derived from waste streams of other food production sectors, thus making them sustainable and affordable. Further studies are necessary to formulate locally sourced diets and determine the efficacy of locally manufactured aquafeeds on aquaculture production systems in the region.

Keywords: Tropical Aquaculture, Aquafeeds, Unconventional Ingredients

Introduction

The Bahamas, like most of the islands in the Caribbean, is a notoriously food insecure country. More than 90% of food is imported, accounting to a cost of nearly USD 1 billion annually, whereas exports of food sourced and grown in the Bahamas costs upwards of USD 61.6 million [1, 2]. The disparity between these figures is reflective of the country's lack of self-sufficiency and reliance on produce outside of its own borders. Due to the food insecurity demonstrated in 2022 import and export values, the Government of the Bahamas recently committed to increasing investments in the agricultural and fisheries sectors [1]. which could improve the presence and yield of the industry. It is essential in regions facing climatic and environmental challenges to assess alternative methods of food production to identify the techniques which are achievable to be implemented and able to contribute to improving food security. The importance of this is highlighted in the current climate of global warming resulting in exacerbated natural disaster frequency, including drought periods [3], and the recent COVID-19 pandemic resulting in major disruptions to supply chains globally [4].

Aquaculture, the cultivation of aquatic organisms, is an environmentally conscious method of aquatic food production that aids in protecting and rebuilding species stocks and habitats [5]. The industry is rapidly becoming a popular solution to addressing food security and income at both local and global scales and has been identified as the fastest growing food production sector [3]. Since 2000, aquaculture showed an annual growth rate of 5.8%

[6], supplying upwards of 50% of all fish and seafood consumed. This amounted to $263.6 billion in revenue and supported the livelihoods of an approximated 20.5 million people globally [7].

While the sector continues to expand globally, the Caribbean region has experienced a drastic decline in aquaculture production over the last two decades with the Caribbean contributing only 0.05% to the global aquaculture production recorded [8]. In the Bahamas, there is very little aquaculture practiced currently, with most of the production being the farming of saltwater species such as spiny lobsters, groupers and snappers, and freshwater farming of tilapia in aquaponics systems [9]. Over the last five years, the volume of tilapia and other freshwater fish imported into the Bahamas has increased by 30%, with over 300,000 USD being spent on freshwater fish imports in 2022 [6]. There are several barriers to the growth of the aquaculture sector, including but not limited to a lack of policy and infrastructure [10]. Another major barrier to the growth of aquaculture is the cost and access to inputs such as feed which can account for 40-75% of production costs [11, 12].

Previously, a study on the feasibility of spiny lobster aquaculture in the Caribbean suggests that the venture is impractical unless more affordable inputs can be sourced [13]. Additionally, an assessment of the profitability of aquaculture in Nigeria revealed that 91.6% of the cost of production was incurred by feed, labor and seed material [14]. This report went on to state that making make aquaculture a feasible economic venture required farmers to explore producing feeds using locally sourced inputs. A report out of St. Lucia also suggests that many factors influence the growth of aquaculture including cost of inputs and encourages the recycling of local raw materials as feed inputs as a means of making the industry more sustainable [15]. This highlights the need for the exploration of local feed production as a means of reducing the cost of aquaculture production, thereby encouraging the participation of more farmers and a boost in the local economy.

Typically, feeds used in aquaculture consist of fishmeal and soybean meal as their primary sources of protein. Proteins are the most expensive feed ingredients, with fishmeal being the most expensive protein option [16, 17]. Most of the fishmeal used in aquafeeds is produced from pelagic fish, thus making it an unsustainable practice, especially when the rate of expansion of the industry is taken into consideration [18, 19]. Fishmeal production occurs primarily in South America, European and Asian countries and soybean meal production is dominated by China, the United States, South American countries, such as Brazil and Argentina and the European Union [18, 20]. Other common ingredients in aquafeeds are corn and wheat as the carbohydrate components, which are also predominantly produced in the United States, Asia and South America [21]. Proteins and carbohydrates constitute 35-70% of all aquafeeds, all of which are typically imported into the Caribbean to facilitate local feed production [22]. The investigation of substitutes that can be sourced locally would potentially contribute to a more affordable product for farmers and would also be more sustainable for the industry as well as the global climate crisis through a reduction in the need for imports to support aquaculture production.

This literature review assesses the nutritional analysis, processing, storage and usage of a variety of unconventional ingredients that can be used in the formulations of aquafeeds for aquaculture production in the Caribbean. Several of these ingredients have been explored in various capacities in different parts of the world including the Caribbean region and Africa and have shown some level of success as comparable or superior aquafeed ingredients.

Methodology

The primary objective of this review is to conduct a comprehensive theoretical analysis aimed at identifying suitable unconventional substitutes for traditional fish feed ingredients. This analysis will specifically aid in the development of a specialized feed for the aquaculture of Red Nile Tilapia in The Bahamas and the wider Caribbean region. The review process will encompass several key stages:

1. **Literature Search and Selection and Identification of Potential Ingredients:** A systematic literature search will be conducted using databases such as PubMed, and Google Scholar. The search will focus on peer-reviewed articles, review papers, conference proceedings, and relevant reports published in the last 30 years. Keywords for the search will include "fish feed substitutes," "aquaculture feed alternatives," "sustainable aquafeed," "Red Nile Tilapia nutrition," and specific substitute ingredients identified in the research, particularly protein and carbohydrate sources. These ingredients will include plant-based proteins (e.g., moringa leaf meal), insect meal, and various waste products (e.g., fish offal meal, agricultural by-products). Criteria for selection will be based on the availability, accessibility, and sustainability of these ingredients in the Bahamian context.
2. **Evaluation of Nutritional Value and Feasibility:** Each identified ingredient will be evaluated based on its nutritional composition, including protein, carbohydrate and lipid content. This evaluation will consider comparative studies and experimental trials that report on the growth performance, feed conversion ratios, and health status of fish fed with these alternative ingredients. Particular attention will be paid to studies involving the Nile Tilapia. The feasibility will be assessed by success stories involving the use of these unconventional ingredients in aquafeed and will include examining case studies, pilot projects, and commercial implementations across different regions. Factors contributing to the success or failure of these trials, such as formulation techniques, inclusion rates, and economic considerations, will be critically analyzed. The feasibility of sourcing these alternative ingredients in The Bahamas and the wider Caribbean region will be examined. This will include investigating local agricultural production, waste management systems, and potential for developing supply chains for these ingredients. The goal is to ensure that the proposed substitutes are not only nutritionally viable but also regionally abundant and accessible. This assessment will also take into consideration the required processing and optimal storage of ingredients for effective and safe use in aquafeed formulation.
3. **Sustainability and Environmental Impact:** The review will also focus on the sustainability and environmental impact of using these alternative ingredients. This will involve assessing the life cycle impacts, resource use efficiency, and potential benefits of reducing reliance on traditional fish-

meal and fish oil. By following this structured methodology, the review aims to provide a comprehensive and practical guide for developing sustainable and effective fish feed substitutes for Red Nile Tilapia aquaculture in the Caribbean. The findings will contribute to the advancement of aquaculture practices in the region, promoting sustainability and economic viability.

Results and Discussion

Alternative ingredients for aquafeeds were determined using the outlined methodology and summarized into a list of potential components that will work towards creating a one hundred percent locally sourced feed that contains all the nutrient contents, protein and carbohydrates to ensure optimal growth of the Nile Tilapia. The proper steps for drying and storing the samples is included for the intentions of building a supply that will later be used in a multitude of feed ratios and put through trials.

Insect Larvae

Black Soldier Fly Larvae

Black soldier fly (Hermetia illucens) is a true fly species that originates from the Americas but can be found worldwide [23]. These flies thrive in warm climates, making them ideal for cultivation in the Bahamas and the wider Caribbean, where they are present naturally. In the adult stage, these flies only consume water and pose no threat to humans as vectors for diseases or as pests to agriculture. The larvae feed on organic material and, due to their long larval stage of three weeks, act as major decomposers, consuming a larger volume of waste than other fly larvae. These flies are currently being used in some organic waste management systems [23]. Their preferred diet comprises fruit and vegetable waste, and manure or various livestock, such as poultry, swine and equine. They are also known to consume other waste products such as food industry waste, fish offal, and grain byproducts [24, 25].

The nutritional content of the dried larvae is dependent on the quality and quantity of food material provided to the larvae [24]. Black soldier fly has been used as a direct food source for certain livestock, such as chickens. The larval meal has been recognized as a partial or total substitute for a fish meal and fish oil in feed for fish and other livestock due to their protein and lipid rich content [23]. The use of the BSFL in the feeds has shown positive impacts on growth parameters of fish. Some studies have seen success with 100% fishmeal replacement with BSFL meal where plant proteins make up the balance of the feed protein requirements [26]. Additionally, the rearing of the BSFL is primarily carried out using biodegradable waste; thereby performing two eco- friendly functions of waste management and fishmeal substitution in aquafeeds. The illustration below, extracted from a report by Mohan et al. (2022) highlights the use of BSFL as a waste processor and then ultimately as a viable substitute for fishmeal in aquafeeds.

Housefly Larvae

Houseflies (Musca domestica) are pests that occur in most parts of the globe where humans exist and have also been associated with animal husbandry [27]. Their larvae, referred to as maggots, however, have shown much nutritional (e.g., high quality protein, fats, vitamins, minerals and other nutrients) and pharmacological properties [28]. They are one of the easiest larvae to rear by exposing substrate (e.g., food waste and animal manure) to allow naturally occurring flies to lay eggs [29]. In a similar manner to the black soldier flies, maggots can also aid in waste management through the breakdown of organic waste material. Feeding trials conducted in one study with varying percentage substitutions of maggot meal (magmeal) in aquafeed for Nile tilapia showed no significant difference in feed uptake up to 100% substitution [25]. Total substitution of fishmeal, however, did show lower growth parameters and an increased feed conversion ratio, which is an assessment of the conversion of feed to body mass [30]. A comprehensive evaluation of replacing fishmeal with housefly magmeal in the diet of Nile tilapia (Oreochromis niloticus) reported equivalent growth performance, flesh quality, and innate immunity [31]. Other studies also suggest that partial fish meal substitution of up to 70% resulted in comparable growth parameters in tilapia, thereby making it a viable ingredient, even though it cannot be used as a total substitute for fishmeal [32, 33].

Fish Discards

At present, fish discards from local artisanal fisheries pose an environmental threat by polluting the sites where they are discarded into and interfering with the natural trophic chain in these areas [34]. This is because the waste parts such as heads, bones, guts, scales and other undesirable parts of fish and crustaceans are discarded in near shore waters by fishers before fish are sold, which inherently disrupts feeding patterns of scavengers and predatory species [10]. The discards typically attract those species, as it is easier to consume these readily available food sources rather than hunting and catching prey, thereby influencing ecosystem-wide changes, particularly with respect to the balance of species at various trophic levels [35]. In the Bahamas and other Caribbean islands, it is common on fishing docks to see fishers cleaning catch prior to selling their catch and disposing of the waste material in the water surrounding the dock.

Fish offal meal, derived from discarded portions of fish that are deemed unfit for human consumption, has been investigated as a potential substitute for traditional fishmeal in freshwater fish feed diets. Several trials have been conducted to explore the efficacy of using varying percentages of fish offal meal as a replacement for fishmeal. These studies have reported success across multiple species, including catfish, carp, and tilapia, demonstrating that fish offal meal can effectively replace fishmeal without compromising growth and health outcomes. Research by Mutharasi et al. (2019), Farahiyah et al., (2015)and Obasa et al. (2009) supports the viability of fish offal meal as a substitute for conventional fishmeal in aquaculture diets.

Moreover, the suitability of fish waste as a protein source has been reported by Goddard et al. (2008), who specifically identified fish offal meal as a beneficial component in the diets of juvenile tilapia. These findings highlight the potential of fish offal meal to serve as a sustainable and effective alternative to traditional fishmeal, thus contributing to more efficient and sustainable aquaculture practices.

Moringa

Moringa (Moringa oleifera) is a fast-growing plant commonly found in tropical and subtropical regions and is a member of the brassica (cabbage) family. It is referred to as the ‘Tree of Life’ due to its abundance in nutritional and medicinal properties [36-38]. It is commonly grown on all Caribbean islands due to its benefits not only to humans, but its use as fodder for livestock [39]. In the Bahamas, it is commonly found in residential spaces and is being cultivated commercially at a small scale for further processing into dietary supplements.

While different parts of the plant have varying nutrient profiles, moringa is known for its high nutrient and mineral content, antioxidant, omega 3 and 6 fatty acids, amino acids, β-Carotene and anti- inflammatory properties [36]. Moringa also possesses antimicrobial, anti- hyperglycemic and anti-cancer properties. Proximate analysis of the leaves revealed that moringa contains crude protein ranging from 23-30% and contains 10 essential amino acids. The crude fiber is <5.9% (lower than soybean meal 7.3%) which suggests higher palatability for fish. Lipid content is approximately 7.09%, and it contains 12% minerals such as potassium(13500 mg/kg), iron (318.81 mg/kg), magnesium (190 mg/kg), calcium (24,700 mg/kg), phosphorus (4,400 mg/kg) and zinc (22.05 mg/kg), which is higher than soybean meal and corn, and is rich in phytochemicals which help build disease resistance [40, 41].

Extensive research has been conducted into the incorporation of Moringa Leaf Meal (MLM) in the diet of tilapia, revealing several notable benefits. Studies have shown that MLM is associated with improved growth indices in tilapia, including increased body mass gain, specific growth rate, length gain rate, and feed conversion ratio. Furthermore, MLM has demonstrated properties as a growth promoter and a natural anti-stress phyto-therapy [42]. In addition to these benefits, Moringa Leaf Meal has been successfully tested as a complete substitute for soybean meal in tilapia diets. Research by Karina et al. (2015) and Kasiga & Lochmann (2014) supports the feasibility and effectiveness of using MLM as a soybean meal replacement. However, it is important to note that while MLM offers these advantages, its inclusion in the diet should be carefully regulated, as studies have indicated that including more than 5% MLM in the diet can lead to depressed growth in tilapia, as reported by Richter et al. (2003).

Brewer's Spent Grain

Beer is the fifth most consumed beverage in the world and involves the removal of the soluble portion of grain, resulting in a concentrated insoluble product referred to as brewer's spent grain [43]. Globally, 39 million tons of spent grain is produced annually, which accounts for 85% of by-products of beer production [44, 45]. Most islands in the Caribbean region produce beer locally and consequently, spent grain.

The Commonwealth Brewery in the Bahamas produces over 1000 tons of spent grain annually and has indicated an interest in determining potential uses for this abundant waste product (K. Ferguson, personal communication, May 15, 2023).

Brewer's spent grain has been used as a feed ingredient for livestock and fish because of its high protein content (49%), antioxidant and immuno-stimulant properties [46, 18, 47]. Not only is it more cost-efficient than fishmeal, but it also addresses the issue of pollution in the brewing industry [18]. The spent grain can also be used as a substrate for the cultivation of black soldier fly larvae [48].

Banana

Banana plants are spread throughout Southeast Asia, the Philippines, and the Pacific Islands and westward to Africa, the Caribbean and Central America [49]. Bananas were a major agricultural export of several Caribbean islands as recently as the early 1990s and continue to be popularly cultivated in the region [50]. Its cultivation in many warm, humid regions gives the potential as a reliable aquafeed ingredient and has shown to be a suitable partial replacement for corn in feed for tambaqui, a South American freshwater fish [51]. Banana leaves and stems can be utilized in animal feed production in multiple forms [52].

Case studies altering aquaculture diets to include banana or plantain have shown comparable and, in some instances, superior fish growth when compared to traditional aquafeeds [52]. Another study reported positive impacts on feed efficiency, growth parameters and immune response when banana fruit is included at a rate of 5% in Nile tilapia diets [53]. Banana pseudostem inclusion of up to 5% has been seen to have positive impacts on growth and liver health of juvenile tilapia [20].

Cassava

Cassava (Manihot esculenta) is a hardy, heat-tolerant shrub native to the neotropics and ranks highly among the world's most consumed staples [54]. Cassava is grown throughout the Caribbean region [55]. It is easy to cultivate in marginal soils, requiring very little care and is one of the few starches cultivated in several parts of the Bahamas. Proximate analyses conducted on various parts of the cassava plant, outlined in table 1 below, revealed that it had great potential for being a suitable fish feed ingredient for rainbow trout and other freshwater species as a carbohydrate source [56-58].

A study by Dada et al. (2015) observing parameters in Nile tilapia (Oreochromis nilocticus) suggests that cassava tuber feed resulted in less weight gain than traditional ingredients (corn), however, cassava peel as a feed ingredient showed comparative weight gain to corn feeds and can be used as a substitute in aquafeeds. The leaves of the cassava have also been used in aquaculture farming as a feed supplement due to its high protein content listed in the table above [59]. The amino acid profile is similar to that of soybean meal. Additionally, the leaves are also a viable source of vitamins that can be harvested without adversely affecting root production [60].

Sweet Potato

Sweet potato (Ipomoea batatas) is a drought tolerant, highly productive tuberous root crop, commonly grown in the tropics. In the Bahamas it is grown on a small scale through subsistence farming and acts as a staple in human diets. Whilst the root tuber is the most desired part for these diets, all other parts of the plant such as the leaves, roots and shoots can be consumed and is a point of research in the viability of its input as an animal feed ingredient [61].

Sweet potato tubers, when boiled, contain low amounts of protein, fiber and fat but high amounts of digestible energy/carbohydrates and many trace minerals. Sweet potato tuber meal was assessed for its suitability as an aquafeed ingredient and showed positive results in freshwater catfish when used as a substitute for corn/maize [62]. Sweet potato leaf meal has also been explored as a protein and carbohydrate/energy source for tilapia. Partial substitutions of sweet potato leaf meal for both protein and carbohydrate sources in feeds have demonstrated comparable growth to commercial feeds [11].

Guinea Corn

Guinea corn (Sorghum vulgare) is a highly nutritious member of the grass family and grows well in dry, hot regions [63]. The grain is popular in many parts of the world because of its nutrient profile and versatility as a product. It contains high concentrations of carbohydrates, proteins, minerals and vitamins, in addition to providing a range of health benefits [63]. Though not widely grown in the Caribbean, guinea corn can be found on several islands in The Bahamas and is believed to have been brought to the region by Africans during slavery, surviving to date (Thebahamasweekly.Com - Bahamian Artifacts Have A Special Place in Exuma, n.d.).

Proximate analysis on the grain revealed that it contains low fiber and high digestible energy contents, making it a suitable substitute for maize in aquafeeds [64-66]. The leaves of the guinea corn have also been examined for their nutrient content and suitability as a food source for livestock. Further proximate analyses by Lucy and Ifedayo (2012) revealed that the leaves contain high levels of carbohydrates. The starches derived from guinea corn grain have also proven beneficial by acting as a binder for aquafeed pellets [30].

Theoretical Proximate Composition of Protein and Carbohydrate Substitutes

As a point of reference, typical freshwater aquafeeds are made up as follows: moisture (<10%), starch/ digestible energy (30-45%), ash (<8%), protein (28-50%) and lipids (5-25%) (Gule & Geremew, 2022). The following tables contain the nutrient profiles of the commonly used aquafeed ingredients, as well as the proposed unconventional substitutes that can be used to achieve a diet that meets the demands of the fish.

Table 1. Proximate composition of carbohydrate substitutes compared with the conventional ingredients

Proximate composition	Maize/ Corn	Bran (wheat/rice)	Cassava peel	Cassava Tuber	Cassava Leaf	Brewers Spent Grain	Banana	Sweet Potato Leaf Meal	Guinea Corn Grain	Guinea Corn Leaves
Moisture (%)	0	10-15	5.11	61.8	6 to 9	<15	4-6	<15	9	12
Crude Lipid (%)	3.6 10.7	3-22 3-7	2.8	0.8	5 to 13	4-10	0.3-0.8	3.5	2.4	6
Crude Protein (%)	8-11	4-23	6.8	3.1	17.8- 34.8	20-50	6 to 9	22.1	10.1	14.2
Ash (%)	1.4 2.9	8-17 4-24	5.7	2.7	9.1	12		16 11	1.8	8.8
Crude fiber (%)	2.3 5.5	6-14 10-33	26.1	1.5	11.4	30-50	20-30	15.4 8.2	4.7	3.07
Carbohydrates (%)	69.1	32-64	53.3	65	46.1	45-51	85-93	49	72	63.8
References	(Munguti et al., 2006)		(Akinfala et al., 2019; Iheukwumere et al., 2008; Madalla, 2008; Oresegun et al., 2016)			(Fernandes et al., 2022; Gokulakrish nan et al., 2023; Madubuike & Okolo, 2016; San Martin et al., 2020)	(Heuzé & Tran, 2016)	(Adewolu, 2008; Ahmad et al., 2019)	(Bulus et al., 2014; Lucy & Ifedayo, 2012)	

Table 2. Proximate Composition of Protein Substitutes Compared with The Conventional Ingredients

Proximate composition	Fish- Meal	Soybean Meal	BSFL Meal	House Fly Larvae Meal	Fish Offal Meal	Moringa Leaf Meal	Brewers Spent Grain
Moisture (%)	8	13	5.3	5-16	8-10	7	<15
Crude Lipid (%)	9	5	20-35	16-26	13.5	7.09	4-10
Crude Protein (%)	60-72	44-57	32-60	64	54.5	23-30	20-50
Ash (%)	12	6	7.3	11	19.8	12	12
Crude fiber (%)	5.3	32	7.4	10	0.76	<5.9	30-50
References	(ssain et al., 6)	(naszkiewicz, 1)	(Wang & Shelomi, 2017)	(Hwangbo et al., 2009)	(Farahiyah et al., 2015)	(Abdel-Latif et al., 2022; Sahay et al., 2017)	(Fernandes et al., 2022; Gokulakrishna n et al., 2023; San Martin et al., 2020)

Treatment and Storage of Locally Sourced Feed Ingredients

This section looks at the required processing of each of the proposed ingredients for use in pelletized aquafeed formulation. The proper storage for each ingredient is also outlined. It is worth noting that the processing required for most of the ingredients can be done with minimal equipment, for example sun drying

Table 1. Proximate composition of carbohydrate substitutes compared with the conventional ingredients

Product		Treatment	Storage	References
Insect larvae	Black soldier fly	Dry with methods including microwave heating, sand roasting in a pan or drum dryer, or oven at 50 °C for 24 h; then mill into a powdered product.	After preparing, store at 4 °C.	(Kamau et al., 2018; Muin & Taufek, 2022; Tippayadara et al., 2021)
	House fly	Dry in an oven at 60°C for 24 h, other mechanisms of drying referred to in Black soldier fly treatment work but are less efficient. The drying process reduced the larvae mass by 75%. Then mill into a powder.	Meal should be stored at 5°C until used.	(Ogunji et al., 2008; Sankara et al., 2017)
Fish offal/ discards		Wash with clean water and sterilize using an autoclave at 120˚C for 20 min. Dry in an oven at 60˚C for 4-5 days until roughly 10% moisture. Then ground and pulverized into very fine form, less than 1 mm in particle size.	Keep in plastic sample bags and stored in a cool dry storage room at 4°C.	(Farahiyah 2015)
Moringa	Leaves	Room drying is cost-effective and within 4 days leaves should be completely dry. Solar drying in temperatures ranging 35- 55°C should dry in approximately 4 hours. Mechanical drying in electric or gas dryers should be done in temperatures of 50°C- 55°C. Then mill leaves and sieve the leaf powder needed. Moringa leaf powder is sensitive to reabsorbing humidity and therefore is to be dried again at 50ºC for 30 minutes. Moisture content is best below 7.5%	Keep powder cool and packed into clean bags (double bag) and sealed. This ensures freshness and dryness for later use. Store bags in a cool, dry place.	(Ali et al 2017) (Saint Sauveur & Broin, 2010)
Brewer's Spent Grain		Sun dry or oven dried at 60 °C for 24 h. Then finely grind.	Maximum storage duration depends on temperature and moisture: 2-5 days in warm temperature when wet, 5-30 days in cold temperatures when wet. When dry store in plastic bags and refrigerate.	(Fernandes et al., 2022; Thomas et al., 2010)
Banana/ Plantain	Fruit	Dry using one of any options; sun-dried, drum-dried, spray dried, or dried in a cabinet dehydrator. Then grind into powder.	n be stored at 18° C for 1 year.	(Brekke & Allen, 1966)
	Peel & Pseudostem & Leaves	Dry at 50 °C, then mill.	ep in an airtight container at m temperature.	(Ma, 2015; Sagrin & Chong, 2013)
Cassava	Peel	Remove peels, wash then soak for three days. Then spread peels on a clean flat cemented surface and sundried until brittle. Lastly, mill into a meal.	at room temperature.	(Cassava Peels, Cassava Pomace and Other Cassava By-Products | Feedipedia, n.d.; Cheikyula et al., 2020; Madalla et al., 2016)
	Leaves	Chop, let wilt for 3 days then dry with preferred feasible method.	Seal and keep at room temperature.	(Ravindran et al., 1987)
Sweet Potato	Tuber	Dice and blanche with boiling water at 90ºC for 2 min. Dry with preferred method. Oven drying recommended temperature is 105°C. Grind into a powder.	Package and store at room temperature.	(Nicanuru et al., 2015)
	Leaves, Roots & Shoots	Pre-wilt for 1-4 days, thus reducing moisture conten by 40-45%, then sun dry and mill.	Store in an airtight container at room temperature.	(Ahmad et al., 2019; Antia et al., 2006)
Guinea corn	Grain Leaves	Sun drying, natural air-drying and low temperature drying are all options. High temperature or continuous flow dryers can also be used. Mill after it has dried.	Best if stored at 4°C in an airtight container.	(Gardisser, 2001)

Discussion

Sourcing Ingredients and Potential partnerships

Gathering the various unconventional local ingredients with the potential to be suitable aquafeed inputs would require canvassing a wide range of sources, due to their diverse nature and origins. The inputs can all be affordably sourced at little to no cost, when compared to the cost of importing traditional aquafeed inputs. Ingredients such as cassava, banana and plantain peels are waste products, resulting from restaurant and other food preparation practices. Partnerships with restaurateurs or community members would be helpful in sourcing and gathering these materials. The tubers of the sweet potato, cassava, bananas and guinea corn can be bought from farmers and then processed in meals. Alternatively, these crops can be cultivated by interested parties for this specific purpose. Similarly, moringa can be cultivated for this purpose, or foraged from trees that have already been planted.

As only the leaves are required for aquafeed production, the trees would not be adversely affected, thus providing twofold benefits of nutrition and carbon sequestration. Brewer's spent grain is a waste product that can be acquired from local breweries. In Nassau, The Commonwealth Brewery currently distributes spent grain to interested farmers at no cost and has communicated interests in partnering with research institutions to determine potential uses of this waste product. Additionally, artisanal fishery discards can currently be freely acquired from fishers, however their use has the potential to become an additional source of income for these fishers whilst also alleviating the issues of pollution and ecosystem disruption in coastal environments. Partnering in a means to not only process this waste but consequently contribute to the development of another food production sector could be welcomed by companies, boosting their contribution to sustainable development.

The discussed ingredients can be sourced through partnerships with local farmers, fishers, restaurants and other members of the community, which distributes the sourcing responsibility, and simultaneously creates opportunities for different business ventures. Furthermore, the potential for funding and sponsorship from large companies that produce waste products that are viable aquafeed ingredients, such as breweries. The inclusion of their waste materials as a feed input aligns the company with sustainable food production systems and reduces the environmental impacts of their operations [67]. This creates the potential for these companies to receive green seal certificates, thereby building their reputation and boosting stewardship.

The production of local aquafeeds through the utilization of locally sourced ingredients would inherently create a variety of business opportunities [48]. The agricultural sector could be boosted by providing a secure market for products like banana, plantain, moringa, cassava, guinea corn, sweet potatoes, thereby encouraging their cultivation commercially. Insect larvae are another potential business opportunity whereby food and other organic waste, such as manure, can be utilized as substrates for their culture. This process can be practiced year-round and would provide threefold benefits by producing insect larvae that serve as a valuable protein source for livestock, both live and processed into meals, breaking down waste material that would otherwise act as environmental pollutants and producing organic material and soil which can be sold to farms to enhance soil quality.

The concept of utilizing these local ingredients in the formulation of a single feed product could foster partnerships between agriculture, fisheries and aquaculture, creating the opportunity for people to act as connectors in supporting this process. One example of this would be a person on a family island in the Bahamas collecting fish discards from fishers, sun drying the material, and selling to a feed producer in Nassau for further processing into fish meal. This pathway could also provide additional income streams to the producers of the waste materials to be utilized as feed ingredients, due to the resultant increase in the value of the products.

By localizing the production of feed for aquaculture production, the country gains more autonomy over the sector and its holistic development [68]. A major downfall of the region in relation to food production is that focus is typically placed only on the production of raw materials whilst the rest of the value chain remains underdeveloped [69, 70]. Local acquisition of inputs for aquaculture production could result in a higher level of agency among the stakeholders involved, and the ability of the country to better govern the sector through the development of policies and establishment of standards.

Ultimately, the feed produced should be more affordable than imported options which has the potential to encourage more participants in the sector [71, 29]. The growth of the aquaculture industry globally was observed to be directly linked to an increase in small-scale farms in developing regions in the world (FAO et al., 2020), and local feed production has the potential to make aquaculture farming at varying scales more popular in the Caribbean region.

Conclusion

This review has assessed the potential of several locally grown or sourced ingredients based on their nutritional analysis, processing and storage requirements and overall efficacy for aquafeed formulations for a variety of freshwater finfish species in the Caribbean. The inputs evaluated have the potential to be combined into a feed product comparable to commercial feeds currently being imported in the Caribbean region. Some of the studies mentioned in this review report alternative feed ingredients resulting in a product that outperformed the conventional feeds [52, 27]. However, it is important to note that in most of the reports, the alternative feed formulations reported have only one traditional feed ingredient been replaced by a local, unconventional substitute [72-80].

Further research should explore primarily developing feed formulations involving a total replacement of traditional aquafeed ingredients with the recommended locally sourced alternatives, and secondly to run trials on these developed formulations, comparing their effects on fish growth and health against traditional feeds [80-90]. Finally, the economic viability of a commercial aquafeed venture utilizing these locally sourced aquafeed ingredients would need to be evaluated, ideally resulting in an affordable and accessible feed source for farmers. This would meet the ultimate objective of eliminating the need for importation of feed for aquaculture production in the Bahamas and the wider Caribbean [91-100].

To conclude, with an increased focus on the potential of aquaculture as a strategy for addressing food insecurity, finding alternatives in feeds that are affordable hold the capacity to make the aquaculture sector more accessible to farmers and potentially increase aquaculture production in the region. This increase could result in a boost to local livelihoods and economies, as well as national food security. Improving food security would better equip the Caribbean region to combat the global threats of Climate Change impacts and future pandemics. Furthermore, increased food security would lower the carbon footprint of the region by reducing the reliance on imports, addressing not only UN sustainable development goals of achieving zero hunger and enhancing livelihoods, but also aiding several countries in meeting set targets of enhanced agriculture and food production [101-109].

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