RESEARCH PROGRAM ON Fish

Led by WorldFish

Assessment of existing and potential feed resources for improving aquaculture production in selected Asian and African countries

Led by WorldFish

In partnership with Wageningen University & Research

Assessment of existing and potential feed resources for improving aquaculture production in selected Asian and African countries

Authors

Jeleel Opeyemi Agboola[1], Rodrigue Yossa[2] and Johan Verreth[1]

Authors' Affiliations

[1] Aquaculture and Fisheries Group, Wageningen University & Research, Wageningen, the Netherland
[2] WorldFish, Penang, Malaysia

Citation

This publication should be cited as: Agboola JO, Yossa R and Verreth J. 2019. Assessment of existing and potential feed resources for improving aquaculture production in selected Asian and African countries. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Program Report: FISH-2019-03.

Acknowledgments

This work was undertaken as part of the CGIAR Research Program on Fish Agri-Food Systems (FISH) led by WorldFish. The program is supported by contributors to the CGIAR Trust Fund. Additional support for this work was provided by the Wageningen University & Research.

Contact

WorldFish Communications and Marketing Department, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. Email: fish@cgiar.org

Photo credits

Front cover, pages 24, 28, 30, 34, 36, 38, 58, 60, 64, 71, 75, 78 and 88, Agboola J.O/WorldFish

Table of contents

List of abbreviations

CL	crude lipids
CP	crude protein
CRP	CGIAR Research Program
DM	dry matter
FISH	Fish Agri-Food Systems
GDP	Gross Domestic Product
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
NFE	nitrogen-free extract
ZDA	Zambia Development Agency

1. Executive summary

This report provides a comprehensive assessment of existing and potential feed resources for improving aquaculture productivity in Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia. These countries depend heavily on imports for their supply of quality feed ingredients. The viability and feasibility of ingredients for aquafeed production are scrutinized based on a number of criteria, including availability (more than 1000 t per year), affordability, nutritional value, associated constraints (presence of antinutritional factors and mycotoxins), feed-food competition, environmental impact and sociocultural implications. A comprehensive literature search (both grey and peer-reviewed) coupled with national and international databases were used to create lists of available feed ingredients in each country. Additional information was derived through administration of semi-structural questionnaires to fish farmers, feed manufacturers, ingredient suppliers and other feed experts. In general, ingredients of plant origin are commonly available in the countries surveyed. The most common plant protein sources are soybean meal, mustard oil cake, sesame meal, sunflower meal, groundnut cake, copra cake, palm kernel cake and cotton seed meal. Animal protein sources are limited to by-products such as poultry meal, feather meal and blood meal. In addition, energy and fiber ingredients are abundantly available and are mainly of plant origin. Novel feed ingredients such as insects, algae, worms and single-cell proteins could be considered as future feed ingredients once they are deemed available. Information on nutritional composition and digestibility of ingredients produced in the targeted countries is scarce, and where it exists it is nonexhaustive and disjointed. Therefore, holistic nutritional analyses of these ingredients are recommended in the future. Moreover, substantial efforts should be dedicated at improving the use of these ingredients in the feeds for various fish species cultured in each country.

2. Introduction

Global aquaculture is projected to increase 50% by the year 2030 (Falch 2014), and like any other terrestrial farming activity, aquaculture is totally reliant on the provision and supply of nutrients. Feed accounts for an estimated 40%–60% of total costs in aquaculture enterprises, and growth in fish production requires concomitant growth in feed inputs as well. In most developing countries, there is a lack of sufficient quality feed ingredients, especially fishmeal and fish oil, and dependency on imported feed resources increases the cost of production, particularly for smallholder farmers. Furthermore, the escalating price of these ingredients, as well as the dwindling supply of fish by-catch, suggests that continuous reliance on imports would be unsustainable in the near future. Therefore, feed manufacturers have to look for locally available sustainable feed resources.

In this regard, the CGIAR Research Program (CRP) on Fish Agri-Food Systems (FISH) was established. WorldFish executes it in collaboration with other research partners, including Wageningen University. FISH is composed of two flagships: one on resilient small-scale fisheries and the other on sustainable aquaculture. The latter flagship contains a cluster of research activities on feed and fish nutrition. Within this cluster, an inventory of local feed ingredients in six target countries (Bangladesh, Myanmar, Malaysia, Nigeria, Egypt and Zambia) was considered as the first step in developing a research program on fish feeds and nutrition. This inventory will help identify sustainable alternative feed ingredients, which must not only be nutritionally reliable as replacements for either fishmeal or fish oil, but they must be affordable and readily available year-round. This report provides a comprehensive assessment of existing and potential feed resources for improving aquaculture productivity in the six focal countries. The viability and feasibility of these ingredients for aquafeed production are scrutinized based on a number of criteria, including availability (over 1000 t per year), affordability, nutritional values, associated constraints (presence of antinutritional factors and mycotoxin), feed-food competition, environmental impact and sociocultural implications. Based on this overarching analysis, recommendations were provided to WorldFish on potential ingredients for aquafeed production. It may lay the foundation for the next research phase in the FISH CRP, where various research activities will ascertain the nutritional values of some of these promising aquafeed ingredients.

3. Methodology

The assessment focuses on Bangladesh, Malaysia, Myanmar, Egypt, Nigeria and Zambia, which are the focal countries of the FISH CRP. For each country, quantitative data on the agricultural production of raw materials and by-products was used to create a database of locally available feed ingredients. This was achieved through an extensive literature review (both grey and scientific) using search engines such as Google Scholar, Web of Science, Scopus and Google for collating the appropriate reports and peer-reviewed articles necessary to establish the database. Additionally, national data on availability and other necessary secondary information on a particular feed ingredients produced in each country was collated from the databases of different organizations, such as the World Bank, FAOSTAT, Indexmundi and relevant national

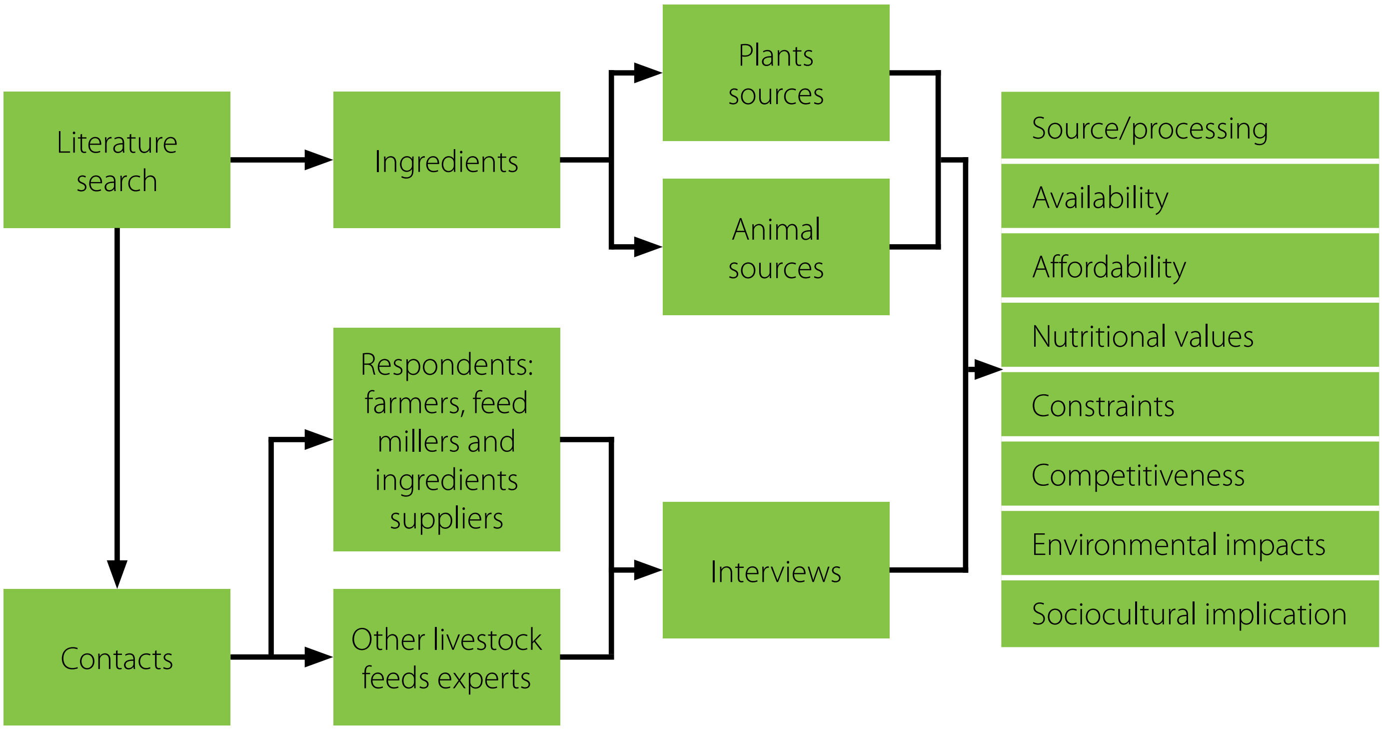


Figure 1. A flow chart of the methodology used to assess the available feed resources in each country.

agencies in the corresponding countries. A cross-CGIAR dialogue was initiated with the International Livestock Research Institute (ILRI) and the International Institute of Tropical Agriculture (IITA) to have a holistic approach during this inventory. Additionally, from the literature research, contacts were established (Appendix 1) with relevant stakeholders, such as feed producers, feed suppliers and farmers. These contacts were used to derive additional information through oral interviews and the use of semi-structured questionnaires. To avoid a poor response rate, selected stakeholders were first contacted via phone, email or trusted intermediaries to determine their willingness to participate in the interview or to answer questionnaires. The questionnaires administered are as represented in Appendix 2. A flow diagram of the methodology adopted is illustrated in Figure 1, while Table 1 shows the range of nutrient composition expected in alternative ingredients before consideration as viable alternatives to fishmeal. However, in this report, ingredients with more than 20% crude protein are considered as protein sources for aquafeed.

Nutrient	Nutrient content in fishmeal (%)	Target range of nutrient in alternative ingredients (%)
Crude protein	65–72	48–80
Crude lipid	5–8	2–20
Fiber	<2	<6
Ash	7–15	4–8
NFE	<1	<20
Starch	<1	<20
Nonsoluble CHO	None	<8
Arginine	3.75	>3
Lysine	4.72	>3.5
Methionine	1.75	>1.5
Threonine	2.5	>2.2
Omega-3 fatty acids	~2	-

Source: Gatlin et al. 2007.

Table 1. The range of nutrient composition expected in alternative ingredients before consideration as viable alternatives to fishmeal.

4. Regional review: Asia and Africa

This section summarizes the trends and development of Asian and African aquaculture in relation to feeds and feeding management, with specific references to the target countries. Key findings are highlighted based on the magnitude of production and the relative importance of each country on a global scale, its growth rate and expected demand in the future, percentage of fed aquaculture and overall trends of aquafeed and development in these two continents. In both Asia and Africa, fish feeding can be broadly categorized into extractive (nonfed) and fed aquaculture. Extractive aquaculture is common in traditional extensive ponds, in which fish growth is totally dependent on the natural productivity of the culturing environment. Fed aquaculture entails the external supplementation of feed ingredients either in the form of a single feed ingredient or (more commonly) in the form of compound feeds. Fertilized ponds are somewhere in between because although they are not fed, some nutrients are supplied. Apart from fertilization, semi-intensive aquaculture also includes ponds where fish are fed nutrient-diluted and often nutritionally unbalanced feed as supplementary feeds. The nutrients that are insufficiently present in the feeds are being sourced from natural food in the pond (a concept known as nutritious ponds in Vietnam). The cultivation system based on the stocking density of culture organisms, level of inputs and the degree of management can be broadly classified into extensive, semi-intensive and intensive systems, as shown in Table 2. More detailed information for each country is provided in the country reviews.

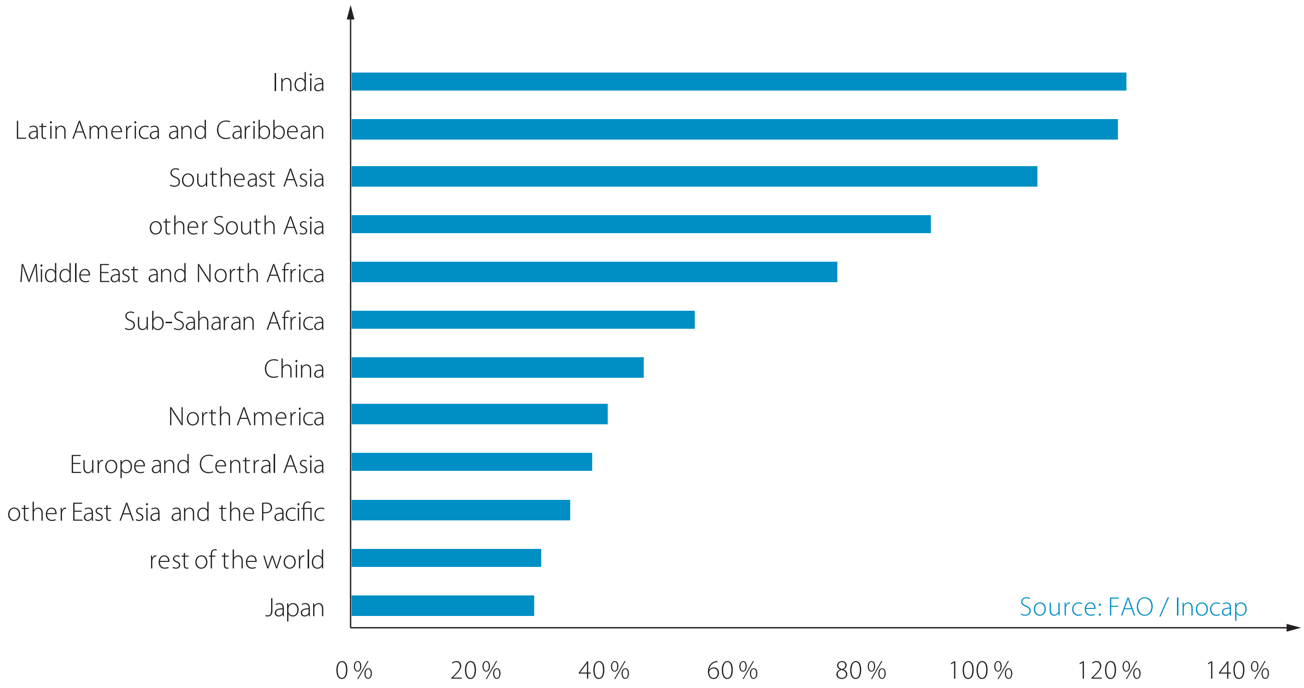
Parameters/Characteristics	Extensive	Semi-intensive	Intensive
Containment	Earthen ponds	Earthen ponds	Earthen ponds, cages, concrete ponds, raceways
Stocking density	Low (e.g. 5,000–10,000 shrimp postlarvae/ha/crop)	Moderate (e.g. 50,000–100,000 shrimp postlarvae/ha/crop)	Very high (e.g. 200,000–300,000 shrimp postlarvae/ha/crop)
Species cultured	Monoculture/polyculture	Monoculture/polyculture	Monoculture
Engineering design and layout	May or may not be well laid out	With provisions for effective water management	Very well-engineered system with pumps and aerators to control water quality and quantity
	Very big ponds	Units of manageable-size (up to 2 ha each)	Small ponds, usually 0.5–1 ha each
	Ponds may or may not be fully cleaned	Fully cleaned ponds	Fully cleaned ponds
Fertilization	Used to enhance natural productivity	Used regularly with lime	Not used
Supplementary feeding	Not used	Farm-made/compound feed	Compound feed
Capital costs	Low to medium	Medium	High
Labor requirements	Mainly family labor	Medium requirements of external labor	Medium to high requirements of external labor
Pond management	No/little management	Moderate management	Maximum management
Production output	Low output	Moderate output	Very high output

Source: adapted from Baluyut and Balnyme 1995; De Silva and Hasan 2007.

Table 2. Types of aquaculture production systems in Asia.

4.1 Development of Asian aquaculture in relation to feed and feeding management

NACA/FAO (2001) and De Silva and Hasan (2007) each conducted a comprehensive review of the development of Asian aquaculture over the previous decades. Table 3 summarizes the outputs of freshwater, brackish water and marine aquaculture from the three target countries in 2015. It is evident that Asia is the worldwide frontrunner in aquaculture production, with China the main contributor (FAO 2017). Aquaculture production by volume and value has increased over the past 10 years, though the rate of increase is declining in some of these countries (FAO 2017). The rate of development expected in each subregion of the world is represented in Figure 2. The growth of Asian aquaculture can be attributed to genetic improvements in a number of species, improved management practices, improvement in disease prevention and control, and improvement in feed formulations. In 2006, an estimated 54%



Source: Falch 2014.

Figure 2. Forecasted percentage change in aquaculture production by regions (2010–2030).

	Bangladesh	Myanmar	Malaysia	Asia	%Asia	World
Production (10,000 t)						
Brackish	18.1	0.0	11.4	503.9	90.2	558.9
Freshwater	188.0	94.4	11.2	4,212.0	95.4	4,416.1
Marine	0.0	5.6	28.0	1,758.6	82.4	2,133.4
Total	206.0	100.0	50.6	6,474.6	91.1	7,108.3
Value (USD million)						
Brackish	988.6	0.0	599.3	19,935.8	76.5	26,049.4
Freshwater	4,161.4	1,314.2	204.4	82,430.1	92.6	89,039.2
Marine	0.0	330.7	46.4	9,631.6	22.4	43,039.1
Total	5,150.0	1,644.9	850.2	111,997.5	80.5	139,148.8

Source: FAO 2017.

Table 3. Freshwater, brackish water and marine aquaculture production by volume and value (excluding aquatic plants) in Bangladesh, Myanmar and Malaysia (2015), compared to production in Asia and World.

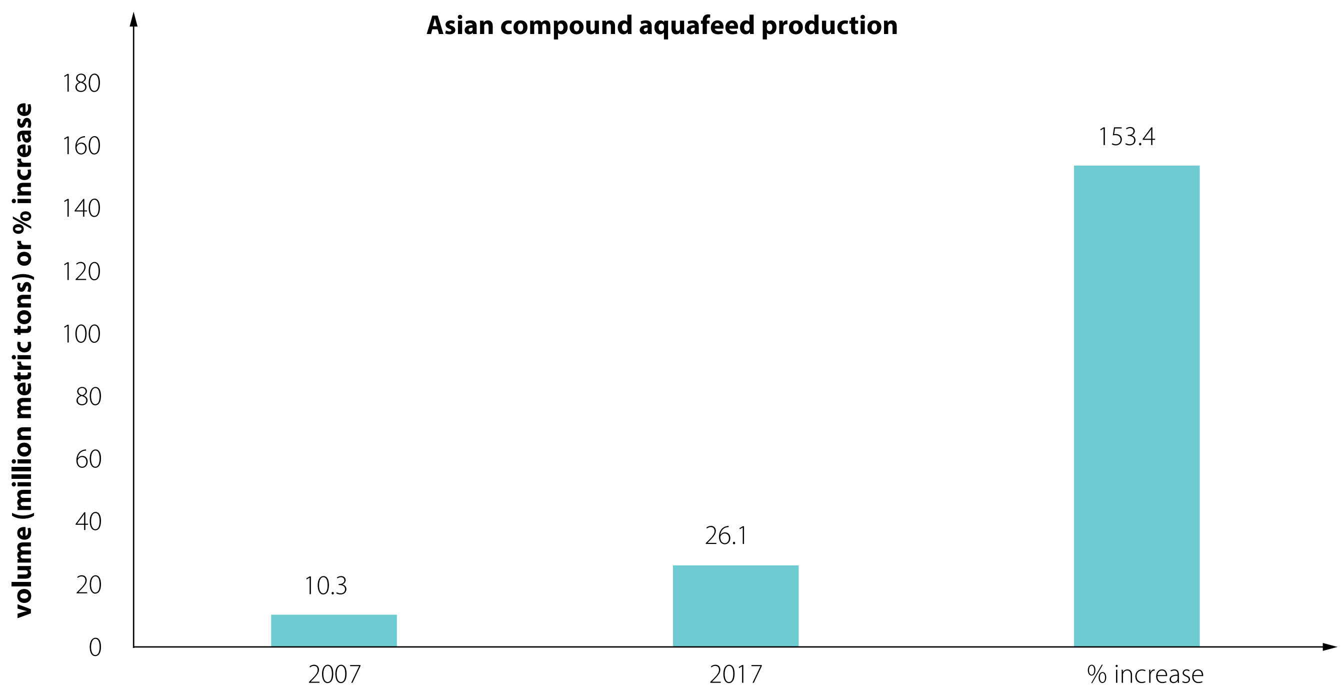
of the total Asian production was based on fed aquaculture (Rana et al. 2009). With the recent development in the region's aquafeed sector, it is assumed that the proportion of fed aquaculture production is far greater than the levels from 2006.

4.2 Trends of aquafeed and feeding in Asia

A few years back, the Asian aquaculture sector was, to a large extent, dependent on farm-made feed formulation and manufacturing. In fact, despite the unaccounted feed usage in backyard pond culture and the exclusion of some countries with limited aquaculture activities, a conservative estimate of aquafeed in Asia showed higher inclusion of farm-made feeds compared to commercial feeds (De Silva and Hasan 2007). The formulation of these feeds differs considerably based on the availability and cost of ingredients, as well as the preference and objectives of the farmers. Although farm-made feeds significantly vary from farm to farm, in general they are composed of basal ingredients, such as soybean meal, wheat bran or rice bran, supplemented with fishmeal or with an ingredient that closely matches the composition of fishmeal (De Silva and Hasan 2007). About 20 million metric tons of farm-made feeds were produced in Asia in 2007 (De Silva and Hasan 2007). Likewise, compound aquafeed production leapfrogged from about 10.3 million metric tons in 2007 (De Silva and Hasan 2007) to about 26.1 million metric tons in 2017,[1] representing approximately a 253% increase (Figure 3). Commercial feeds, to a significant extent, are dependent on the use of fishmeal and fish oil, and these two ingredients are largely unavailable in Asia. Asia produces 17% and uses 47% of global fishmeal production, which positions it as the biggest user of fishmeal (De Silva and Hasan 2007). Therefore, to augment this difference, countries in Asia rely on imported fishmeal from other parts of the world. However, as fishmeal/fish oil resources are limited, the increasing aquaculture production in this region makes the search for locally available feed resources (both conventional and nonconventional) urgent. Comprehensive lists of available feed resources in the different target countries are shown in Tables 4 and 5.

4.3 African aquaculture development in relation to feed and feeding management

Unlike Asia, aquaculture production in Africa on a global scale is low, but its role in ensuring food security in this region cannot be overemphasized. Fish consumption has played an important role as a source of dietary protein and minerals in this region, and fish provides approximately 22% of dietary protein in sub-Saharan Africa (FAO 2016).



Source: De Silva and Hasan 2007 and Altech Global Feed Survey (AGFS) (2018).[1]
Data for 2007 was sourced from De Silva and Hasan 2007 whereas that of 2017 was from AGFS. The 2017 data also includes aquafeed production in the Pacific.

Figure 3. Commercial aquafeed production in Asia for year 2007 and 2017.

Ingredient	Bangladesh	Malaysia	Myanmar
Leaf meal			
Leucaena leucocephala	+	+	+
Drumstick leaf meal	+		
Krishnachura leaf meal	+		
Potato	+		
Sweet potato	+		
Khesari seeds	+		
Ipil Ipil leaf meal	+		
Waste leaf meal	+		
Neem leaf meal	+		
Banana blossom	+		
Azolla	+		
Duckweed	+		
Mushroom	+	+	
Water hyacinth	+		
Turi leaf flour			
Lemna spp.			
Algae		+	
Mulberry leaf		+	
Gliricidia sepium		+	
Peel/husk/bran			
Pineapple		+	
Banana peel	+		
Bottle gourd peel	+		
Brinjal peel	+		
Gram husk	+		
Coconut peel	+		
Pea husk	+		
Potato peel	+		
Pumpkin peel	+		
Papaya skin	+		
Rice polish	+		
Rice bran	+	+	+
Cocoa pod		+	
Wheat bran	+		+

Ingredient	Bangladesh	Malaysia	Myanmar
Oil cakes			
Soybean	+	+	+
Mustard	+		+
Sesame	+	+	+
Rapeseed cake/canola	+	+	
Sunflower	+	+	+
Cotton seed meal	+		+
Groundnut meal	+		+
Coconut/copra	+	+	
Til oil cake	+		
Palm kernel meal		+	
Linseed	+	+	
Others			
Maize gluten	+		
Wheat flour	+	+	
Carrot meal	+		
Rubber seed meal	+	+	
Neem seed meal	+		
Bitter melon seed meal	+		
Triricale meal	+		
Maize	+	+	+
Cassava	+	+	
Rice	+	+	
Wheat	+		
Sorghum meal		+	
Broken rice		+	+
Sago		+	
Brewer’s dried grain		+	
Groundnut meal		+	+
Candle nut meal		+	

Note: "+" available in the country.
Source: authors' literature review (2017).

Table 4. Commonly available and potentially useful agricultural by-products and plants for aquafeed in selected Asian countries. (Selection was based on literature review where the experiments were conducted within the country.)

Ingredient	Bangladesh	Malaysia	Myanmar
Fishmeal	+	+	+
Meat meal	+		
Bone meal	+		
Meat and bone meal	+	+	
Shrimp meal	+	+	
Poultry by-product	+	+	
Hatchery by-product	+		
Offal meal	+		
Blood meal	+		
Marine waste	+		
Oyster shell	+		
Blood meal	+	+	
Feather meal	+	+	
Leather shaving meal	+		
Poultry droppings meal	+		
Trash fish			
Mysid			
Squid			
Worm meal		+	
Mussel			
Golden snail	+		
Earthworm	+	+	
Crab meal	+		
Silkworm pupae	+		
Black soldier fly		+	
Cricket		+	
Mealworm		+	
Poultry fat		+	
Animal manure meal		+	
Krill		+	
Anchovy waste		+	

Note: "+" available in the country.
Source: authors' literature review (2017).

Table 5. Commonly available and potentially useful animal by-products for aquafeed in selected Asian countries. (Selection is based on literature review where the experiments were conducted within the country.)

Table 6 summarizes outputs of freshwater and brackish water aquaculture by production and value in the four target countries for 2015. African aquaculture production is increasing, though not rapidly. A growth rate of 50% or more is expected by 2030 (Figure 2). This is because of renewed interest from governments and other stakeholders, technological advancement, genetic improvement programs and, more importantly, the use of improved feeds and feeding methods. Little data is available on current production from fed and nonfed systems, but the recent investment from giant aquafeed producers in different parts of Africa is expected to tilt the scale toward more production from fed systems in the future.

4.4 Trends of aquafeed and feeding ingredients in Africa

The animal feed industry in Africa mainly consists of industrial-scale and small-scale feed manufacturers. The industrial-scale feed producers are dependent on the use of sophisticated machinery, and they produce large volumes of commercial feed per day. The larger proportion of feeds produced by this category are purchased by large-scale commercial farmers, both livestock and aquaculture producers. Conversely, the small-scale feed manufacturers only produce a fragment of the total feed output in Africa but are responsible for the majority of feeds supplied to the larger percentage of small-scale animal producers. This particular category of manufacturers, because of its lower investments and capital outlay, mainly relies on the use of less sophisticated machinery, and feeds are mostly produced based on the specification or formulation of farmers. Overall, on the continent, an appreciable quantity of feeds produced both through small-scale and large-scale feed millers are poultry feeds rather than specific aquafeeds. Until a decade ago, fish feeds were manufactured by the animal feed industry (responsible for producing feeds for terrestrial animals) based on farmers' requests. The low demand for specific aquafeeds made it impossible for the animal feed industry to establish dedicated lines for aquafeed production (Hecht 2007). Therefore, the bulk of fish farmers engaged chiefly in the production of on-farm feed. For instance, in 2005 about 70% of the aquafeed used in Nigeria was farm-made (Fagbenro and Adebayo 2005). However, the upsurge in aquaculture growth in this region over the past decade has led to the emergence of informal small-scale and formal large-scale aquafeed manufacturers (Hecht 2007). Nevertheless, the aquafeed industry is still in the emerging phase in most African countries (except for Nigeria, Egypt and Zambia), and the majority of the fish farmers in Africa are still dependent on small-scale feed producers.

	Egypt	Nigeria	Zambia	Tanzania**	Africa	% Africa	World
Production (1,000 t)							
Brackish	*	0	0	0.4782	14.9759	0.3	5,589.085
Freshwater	*	316.727	22.754	3.514	618.7224	1.4	44,160.54
Marine	0	0	0	0	5.6586	0	21,333.68
Total	**1,174.831**	**316.727**	**22.754**	**3.9922**	**1,772.391**	**2.5**	**71,083.3**
Value (USD million)							
Brackish	1,493.291	0	0	2.9124	1,580.661	6.1	26,049.39
Freshwater	337.7434	904.4457	69.0859	12.4493	1,857.815	2.1	89,039.21
Marine	0	0	0	0	68.7009	0.2	43,039.1
Total	**1,831.035**	**904.4457**	**69.0859**	**15.3616**	**3,507.177**	**2.5**	**139,148.8**

Source: FAO 2017.
**Data is questionable, therefore excluded.*
***Data for Tanzania excludes Zanzibar, which FAO lists separately.*

Table 6. Freshwater, brackish water and marine aquaculture production by volume and value (excluding aquatic plants) in Egypt, Nigeria, Zambia and Tanzania (2015).

Generally, African countries, except Zambia, lack quality feed ingredients, which creates a dependency on imports for supply of quality feed resources. This reliance on imports is in part responsible for the exorbitant prices of feeds, which undermine the profit generated by aquaculture producers in Africa. Therefore, it would be beneficial for the growth of aquaculture in Africa to replace imported ingredients with qualified local ingredients. Quite a number of locally produced ingredients have been identified as potential substitutes to conventional feedstuffs, which are mostly imported in this region. Extended lists of these feedstuffs are shown in Tables 7 and 8.

Ingredient	Egypt	Nigeria	Zambia	Ghana	Tanzania	Kenya
Plant/leaf meal						
Potato by-product	+	+			+	+
Cocoyam/taro		+				
Cassava	+	+	+	+	+	+
Sebania sesban			+			
Tomato by-product	+					
Alfafa hay	+					
Faba bean	+					
Gliricidia leaf meal		+		+	+	
Leucana leucocephala		+	+	+	+	
Berseem hay	+					
Molasses	+		+		+	+
Cowpea seed	+		+			
Guava by-product	+					
Jatropha seed meal	+					
Date meal	+					
Ulva latuca meal	+					
Pterocladia capillacea meal	+					
Duckweed	+	+				
Seaweed	+					+
Moringa leaf/seed meal		+		+	+	
Water fern					+	
Azolla	+				+	
Banana stem/leaf						+
Neem plant		+		+		
Amaranthus cruentus		+	+			+
Telfairia occidentalis						
Water hyacinth				+		
Water leaf		+				
Arrow root leaf					+	+
Spirulina	+					
Mango kernel meal		+		+		+
Cocoa by-product		+		+		
Jackbean		+				
Sargassum spp.	+					+
Locust bean		+				
Baobab leaf				+		
Pawpaw leaf/peel		+		+	+	+
Peel/husk/bran						
Wheat bran	+	+	+	+	+	+

Ingredient	Egypt	Nigeria	Zambia	Ghana	Tanzania	Kenya
Lentil bran					+	
Wheat pollard					+	+
Rice bran		+	+	+	+	+
Maize bran		+	+	+	+	+
Cocoyam peel				+		
Groundnut skin				+		
Yam peel		+		+		
Coffee husk						+
Plantain/banana peel		+		+		+
Maize-cob meal	+			+		
Oil cakes						
Soybean meal	+	+	+	+	+	+
Cotton seed meal	+	+	+	+	+	+
Sunflower seed meal	+	+	+		+	+
Groundnut cake		+	+	+	+	
Rubber seed meal		+				
Rapeseeds/canola seed	+					
DDGS	+					
Sheanut cake				+		
Copral/coconut meal		+		+		
Sesame	+	+			+	+
Linseed/flaxseed	+					
Palm kernel	+	+		+		
Mucuna seed meal	+			+		
Jojoba	+					
Others						
Maize/corn	+	+	+	+	+	+
Nigella sativa (cumin seed)	+					
Rice	+					
Brewers' waste	+	+			+	
Barley	+					
Okara meal	+					
Broken rice	+				+	
Maize gluten feed			+		+	
Guinea corn		+				
Bread waste		+	+			
Millet		+	+	+	+	
Cashew kernel		+		+		
Sorghum		+	+	+	+	+
Brewery yeast			+	+		
Kitchen waste				+		
Pito mash				+		
Rain tree seed meal				+		
Oil palm slurry				+		
False yam				+		
Grist mill waste						+

Note: "+" available in the country.

Table 7. Available aquafeed ingredients of plant origin. Data based on literature review (2017).

Ingredient	Egypt	Nigeria	Zambia	Ghana	Tanzania	Kenya
Shrimp meal	+	+			+	+
Blood meal	+	+	+	+	+	+
Meat meal	+	+				
Meat and bone meal	+	+	+			
Feather meal	+	+	+			
Broken eggs	+					
Animal gelatine	+					
Poultry by-product	+	+				+
Trash fish	+		+			
Fish silage	+		+			
Poultry offal meal	+					
Gambusia meal	+					
Krill	+					
Dried rumen content	+	+			+	+
Fishmeal	+	+	+	+	+	+
Poultry manure	+			+		
Fish visceral meal	+					+
Hatchery by-product	+					
Earthworm	+	+				
Housefly larvae	+					
Maggot meal	+	+		+		
Perinereis cultrifera	+					
Tadpole meal		+				
Crab meal		+				
Grasshopper meal		+		+		+
Termite meal		+	+	+		+
Garden snail		+				
Silkworm		+				
Grub		+				
Mealworm			+			
Mopani worm			+			
Black soldier fly				+		
Shea tree caterpillar				+		
Palm weevil larvae				+		
Crickets				+		
Locusts				+		
Beetles				+		

Note: "+" available in the country.
Source: authors' literature review (2017).

Table 8. Available aquafeed ingredients of animal origin in selected African countries. (Selection was based on literature review where the experiments were conducted within the country.)

5. Country review: Bangladesh

5.1 Introduction

Bangladesh is primarily divided into eight administrative divisions: Barisal, Chittagong, Dhaka, Khulna, Mymensingh, Rangpur, Rajshashi and Sylhet (Figure 4). The country's economy has continued to grow at 6% per year since 1996, and nearly half of its GDP is generated through the service sector.[ii] Exporting garments is the backbone of the Bangladesh's industrial sector, accounting for more than 80% of its total exports, valued at over USD 25 billion in 2016.[2] Agriculture is the mainstay of the economy and remains the largest employer in the country, with about half of the population directly employed in the agriculture sector. It plays a pivotal role in the economy, contributing 17% of total GDP (BBS 2017). Rice is the most important crop cultivated in the country. Other important agricultural products are jute, potatoes, sugarcane, oil seeds and poultry.

5.2 Aquaculture in Bangladesh

Bangladesh is inundated with rich inland waters and river systems, which positions it as one of the most suitable destinations for fisheries and aquaculture in the world. In fact, Bangladesh is among the world's top 10 producers of fish (fifth in 2016) (FAO 2016). The fisheries sector can be broadly categorized into inland capture

Source: *http://d-maps.com/carte.php?num_car=2145&lang=en*

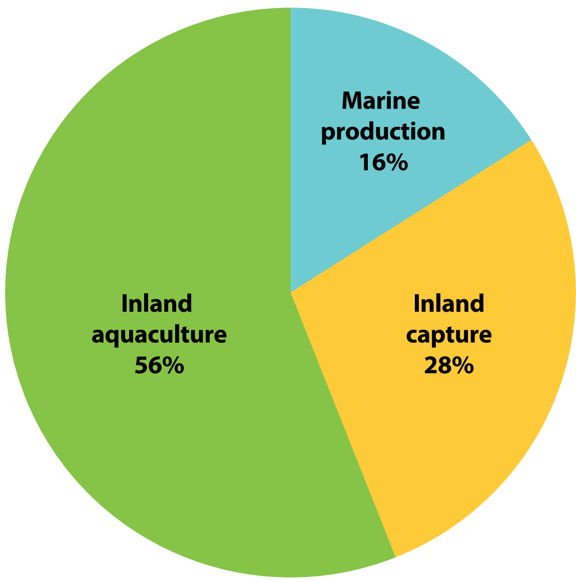
Figure 4. Administrative divisions of Bangladesh.

fisheries, inland aquaculture and marine fisheries. Inland aquaculture makes up 55% of total production (Figure 5). Fish is a very good source of animal protein, and its production generates employment, earns foreign exchange and alleviates poverty. The contribution amounts to 4.92% of total GDP and 5.7% of total export earnings. About 12 million people, including 1.4 million women, are directly or indirectly employed by the sector (BBS 2004). Fisheries and aquaculture are the second-most significant contributors to Bangladesh's exchange earnings, which were valued at USD 605.878 million in 2015 (Shamsuzzaman et al. 2017). Fish and rice are very important in the life of the average Bengali. The two perfectly complement each other in the national diet, giving rise to a popular cliché *Maache-Bhate Bangali* ("a Bengali is made of fish and rice") (Ghose 2014). Fish is responsible for almost 60% of the daily animal protein intake for Bangladeshis (DOF 2016).

Similar to other countries in the world, Bangladesh's production from capture fisheries has plateaued, which is reflected in the dwindling habitat for capture fisheries (a decrease of 160,000 ha between 2003 and 2014), and the increasing habitat for culture fisheries (an increase of 350,000 ha during the same period) (Shamsuzzaman et al. 2017). Inland aquaculture has been rapidly increasing because of new technologies, intensification, improved farming methods and genetically improved species (Planning Commission 2016). Inland aquaculture in Bangladesh has experienced an average growth rate of 8.2% over the past decade, whereas the average growth rate of fisheries within the same period was 5.2% (DOF 2015). The rapid growth of inland aquaculture is expected to be sustained to meet future demand for fish-derived protein. Future aquaculture growth in Bangladesh is complicated by three major drawbacks: seed, feed and extension services (Planning Commission 2016). These constraints have been comprehensively stated and addressed by Shamsuzzaman et al. (2017). The status of aquaculture feed resources is addressed in this technical report.

5.3 Status of the aquafeed industry in Bangladesh

Based on a previous field survey (albeit nonexhaustive) conducted by Barman and Karim (2007), the industrial aquafeed sector produced an estimated 50,000 t of aquafeed annually, mainly for intensive culture of pangasius, monosex Nile tilapia and the Thai strain of climbing perch. Between 2005 and 2007, feed production for shrimp and prawn accounted for about 10,000 t annually. Aside from the industrially produced feeds, a substantial quantity of aquafeed was either farm-made or produced by small-scale feed manufacturers. This makes the annual aquafeed use in Bangladesh to be about 230,000 t (Barman and Karim 2007). The current situation is certainly different, with feed mills making more compound feed after a shift from using



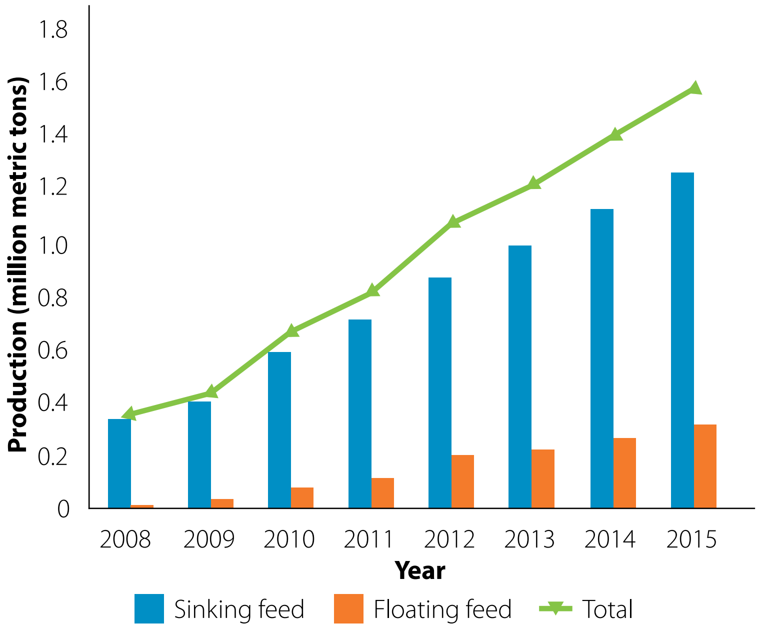
Source: DOF 2016.

Figure 5. Total fish production in Bangladesh per fisheries subsector in 2015.

predominantly farm-made feeds to more quality commercial feeds. Between 2008 and 2012, production of commercial feeds increased by 32%, reaching 1.07 million metric tons, with sinking feeds taking the largest share (81%) ahead of extruded floating feeds (19%) (Figure 6). There are over 100 commercial aquafeed producers in Bangladesh, but the market is dominated by eight to 10 large-scale operators, representing 60%–70% of the total market share (Mamun-Ur-Rashid et al. 2013). Conversely, farm-made feeds are manufactured in local workshops equipped with a simple pellet machinery, used to crush dried fish and maize, then mixed manually with other feed ingredients and mechanically forced through a die to produced spaghetti-like strands that are later sundried or air dried and broken into smaller pieces before feeding (Mamun-Ur-Rashid et al. 2013). Farm-made feeds are often nutritionally imbalanced, and fish require supplemental nutrients from natural food in the pond for better growth. The percentage of aquafeed production per fish species is summarized in Table 9.

5.4 Available feed resources in Bangladesh

A wide variety of feed ingredients, both local and imported, is either used singly or mixed for the general feeding of fish. With the projected upsurge in aquaculture, as seen from the increase in pangasius and tilapia between 2010 and 2015 (Figure 7), the quantity of required feed ingredients will increase concomitantly. The vast majority of these ingredients are procured externally and



Source: Mamun-Ur-Rashid et al. 2013.

Figure 6. Actual and projected aquafeed production in Bangladesh (in million metric tons) (2008–2015).

Type of feed	Quantity (metric tons)
Commercial feed	1,070,000
On-farm feed	300,000–400,000
Share of feed per fish species (%)	
Pangasius feed	60%–65%
Tilapia feed	35%–45%
Climbing perch feed	10%–15%
Shrimp and prawn	2%–3%
Carp	2%–5%

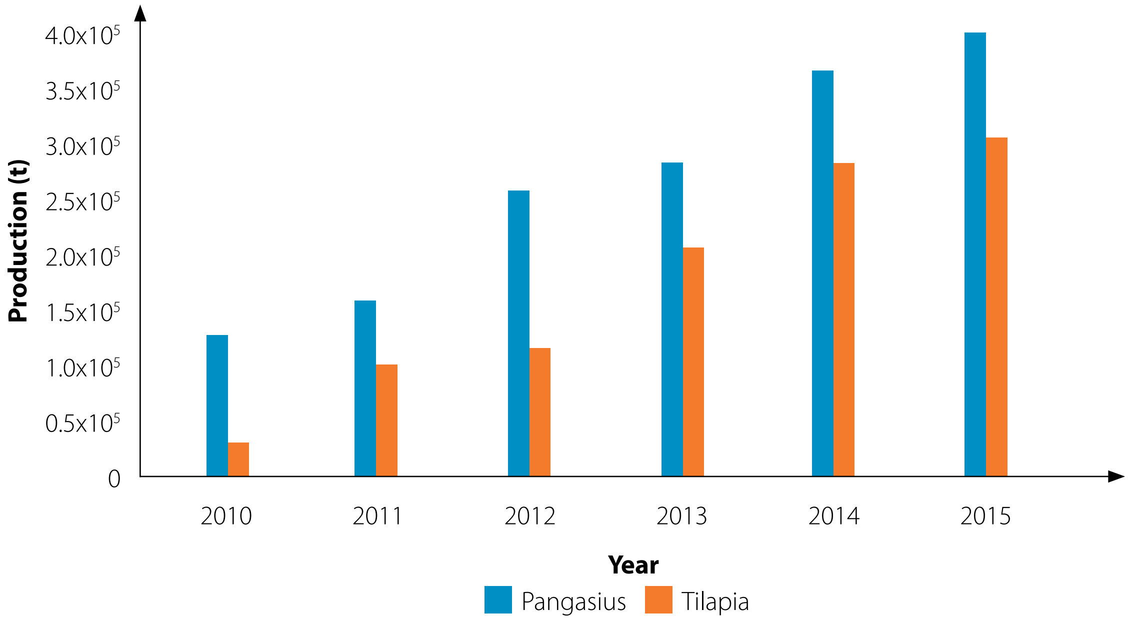
Source: Mamun-Ur-Rashid et al. 2013.

Table 9. Percentage of aquafeed production per fish species.

at exorbitant prices, which increase the overall costs of production for fish farmers. The total crop production in Bangladesh for 2016 is shown in Table 10, and the geographical distribution of the crops within the country is depicted in Figure 8. To the authors' knowledge, there is a paucity of quantitative data on the production of animal ingredients within the country.

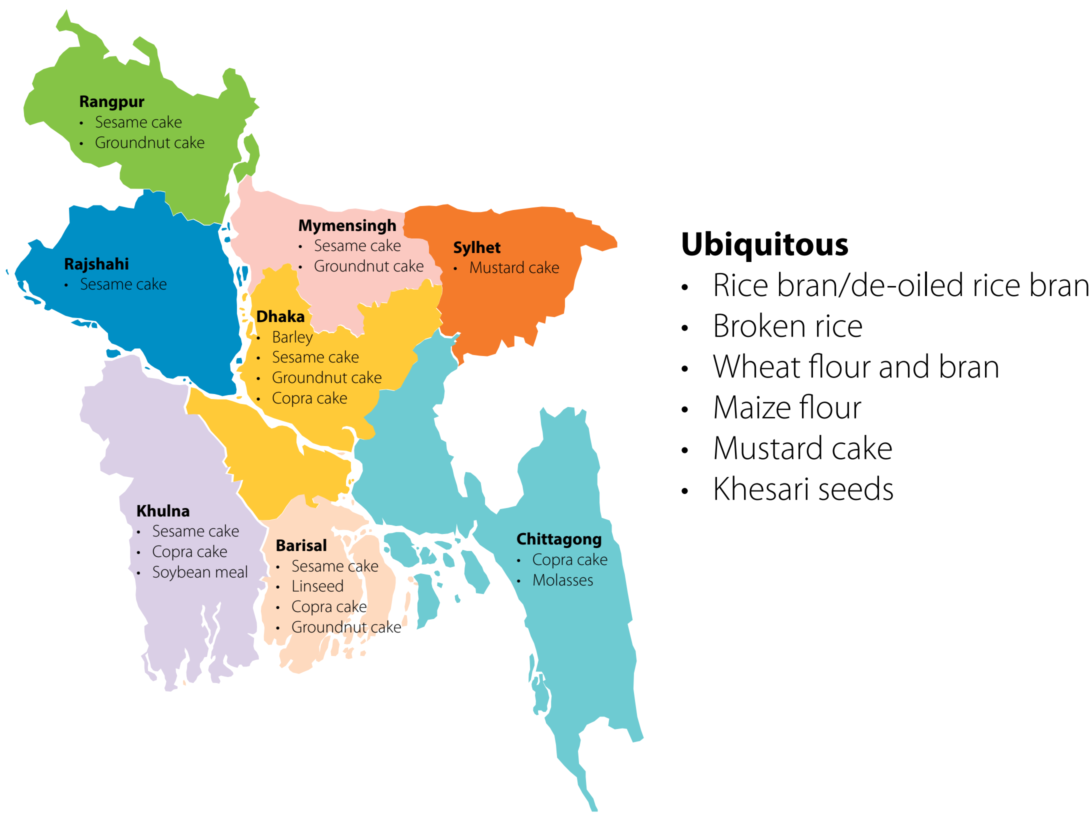
5.4.1 Feed ingredients currently used in Bangladesh

This section contains specific information on a number of selected ingredients from Tables 11 and 12 that have potential to be used in aquafeed. The proximate composition of these feedstuffs is presented in Tables 13 and 14.



Source: Shamsuzzanman et al. 2017.

Figure 7. Production of pangasius and tilapia in Bangladesh (2010–2015).



Source: editable map from: https://yourfreetemplates.com

Figure 8. Crop distribution based on administrative divisions in Bangladesh.

5.4.1.1 Protein sources: Plant origin

Soybean meal and soybean cake

Bangladesh is not among the world's top producers of soybeans. In 2016, about 156,000 t of soybean oil seeds were produced in the country (Indexmundi 2017). However, the production of soybean meal in Bangladesh skyrocketed from 7000 t in 2001 to 870,000 t in 2017 (Indexmundi 2017). Additional soybeans are imported and crushed to augment local demand for soybean meal. City Group and Megna Group have the two largest crushing plants in the country. Currently, the domestic consumption of soybean meal in Bangladesh stands at 1.3 million metric tons, whereas 870,000 t are being locally produced (Figure 9).

Soybean meal, which is a by-product of the extraction of soybean oil, is the most important plant protein used for both livestock and aquaculture, and there is intense competition between the poultry and aquaculture feed sectors for the use of this feedstuff. The nutritional composition of soybean meal usually varies depending on its origin, processing methods, oil extraction methods and remnant oil in the products. Soybean meal produced in Bangladesh contains 39.95% crude protein, 7.21% crude lipid, 5.21% ash, 3.9% crude fiber and 43.72% total carbohydrates (Table 13). Soybean cake is produced after grinding soybean seeds, with little or no oil removal prior to grinding, and is usually

Ingredients	Total annual yield (t)	Seasonality
Cereals products		
Rice	34,710,000	+++
Maize	2,445,000	++
Wheat	1,248,000	++
Barley	7,000	+
Oil cake products		
Coconut	374,000	++
Rape and mustard	362,000	+
Soybean	156,000	++
Khesari seeds	122,000	++
Groundnut	62,000	+
Til/sesame	37,000	+
Tuber products		
Potato	9,474,000	++
Fruit products		
Pineapple	7,200,000	++
Sugarcane	4,207,000	++
Mango	1,162,000	++
Jackfruit	1,031,000	++
Banana	798,000	++
Papaya	130,000	++
Animal origin		
Poultry waste	12,920,000	+++

Sources: Bangladesh Bureau of Statistics 2016; Indexmundi 2017.

Table 10. Crop production in Bangladesh (2016).

Ingredient	Currently used in aquafeed	Source (local or imported)
Maize	Yes	Local
Cassava leaf meal	No	-
Cassava peel	No	-
Wheat	Yes	Local
Wheat bran	Yes	Local
Wheat flour	Yes	Local
Rice polish	No	-
Soybean meal	Yes	Local and imported
Sesame/til oil cake	No	-
Cotton seed meal	No	-
Coconut/copra meal	No	-
Rice bran	Yes	Local
Mustard oil cake	Yes	Local
Potato	No	Local
Khesari seed	Yes	Local
Drumstick leaf meal	No	-
Krishnachura leaf meal	No	-
Ipil ipil leaf meal	No	-
Duckweed	No	-
Broken rice	Yes	Local
Rice	No	-
Banana blossom	No	-
Bottle gourd peel	No	-
Brinjal peel	No	-
Gram husk	No	-
Green banana peel	No	-
Green coconut peel	No	-
Pea husk	No	-
Potato peel	No	Local
Pumpkin peel	No	-
Ripe banana peel	No	-
Azolla	No	-
Oyster mushroom	No	-
Leucaena meal	No	-

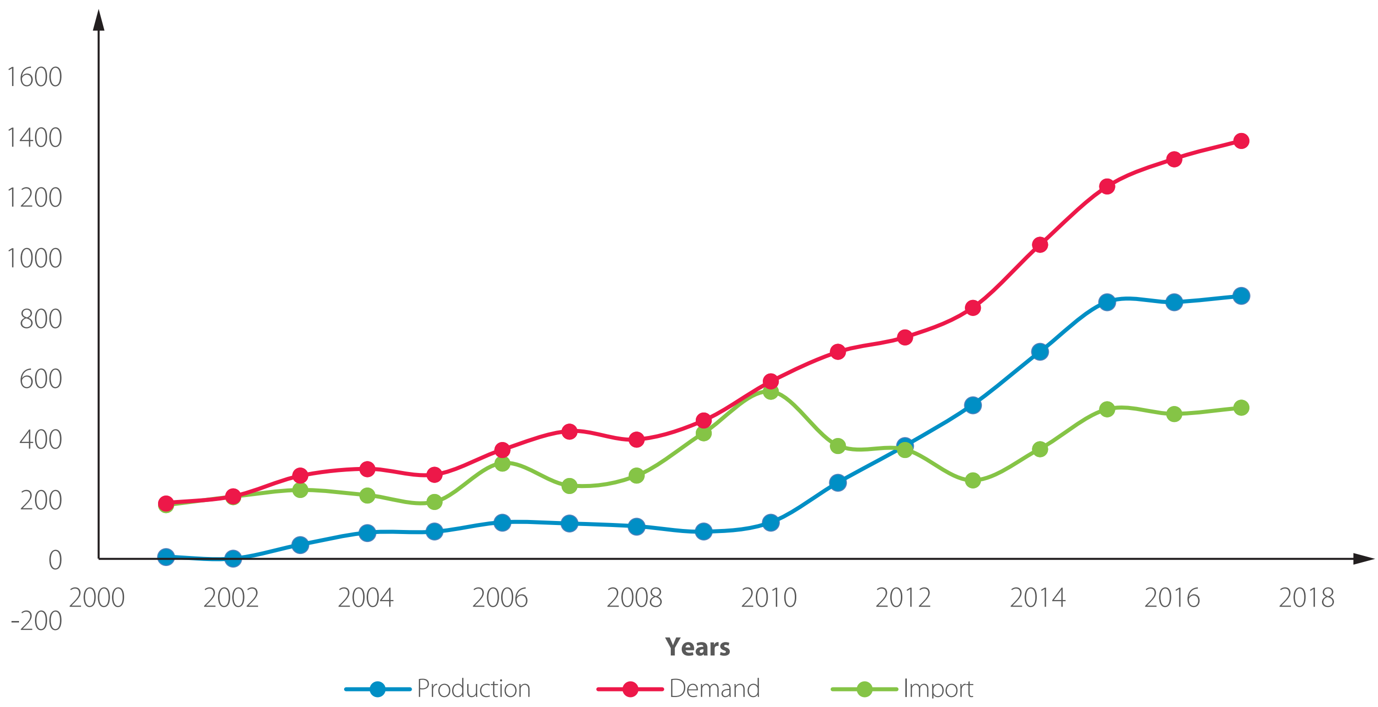
Note: "-" information not available.

Table 11.Ingredients of plant origin available for aquafeeds in Bangladesh.

Ingredient	Currently used in aquafeed	Source (local or imported)
Fishmeal	Yes	Imported
Bone meal	Yes	Imported
Shrimp meal	Yes	Local
Marine waste	No	-
Blood meal	No	Local
Feather meal	No	Local
Leather shavings	No	-
Hatchery by-product	No	-
Poultry offal meal	Yes	Imported
Earthworm	No	-
Crab shell	No	-
Fish silage	Yes	-
Silkworm pupae	No	-
Snail meal	No	-
Dry fish	Yes	Local

Note: "-" information not available.

Table 12. Ingredients of animal origin available for aquafeeds in Bangladesh.



Source: Indexmundi 2017.

Figure 9. Production, demand and imports of soybean meal in Bangladesh (t) (2001–2017).

Ingredient	DM	Crude protein	Crude lipid	Ash	Crude fiber	NFE	References
Maize	89.5	9.7	5.0	7.3	2.5	75.6	a,b,c,d,e
Cassava leaf meal	88.1	12.6	6.7	8.9	13.4	71.8	f
Cassava peel	86.1	2.9	0.6	1.8	1.8	92.9	f
Wheat	89.9	10.2	2.2	11.6	3.0	73.0	a, g
Wheat bran	88.8	16.4	5.7	4.9	NA	NA	h,
Wheat flour	89.6	14.7	2.9	2.3	1.4	78.7	b,h,
Rice polish	90.5	13.8	10.8	9.7	11.5	54.2	b,g,j,k
Soybean meal	89.7	40.0	7.2	5.2	3.9	43.7	b,g,l
Sesame/til oil cake	91.3	32.8	8.1	13.9	5.2	39.9	c,d,h,m
Cotton seed meal	91.9	21.7	9.6	5.0	NA	NA	h,n
Coconut/copra meal	89.3	18.8	11.7	7.3	NA	NA	d,h
Rice bran	89.7	8.4	10.2	15.0	16.3	50.0	h,a,l,e
Mustard oil cake	89.8	32.5	12.0	11.6	9.4	34.5	a,b,e,o
Potato	21.0	2.8	0.2	1.4	4.9	90.7	p
Khesari seeds	90.0	26.7	2.6	5.0	5.0	60.7	h,n
Drumstick leaf meal	97.6	22.2	9.7	10.5	4.7	52.9	f
Krishnachura leaf meal	98.5	16.3	9.5	5.6	37.7	30.9	f
Ipil ipil leaf meal	97.4	26.7	9.4	10.4	0.6	52.9	f
Duckweed	90.8	29.5	4.3	31.5	10.9	23.8	c,f,o,q
Broken rice	86.6	10.6	2.1	2.2	3.1	82.0	r
Rice	87.4	8.4	2.1	2.2	1.6	85.7	r
Banana blossom	8.9	13.8	3.9	10.2	27.4	44.7	s
Bottle gourd peel	6.6	7.0	2.1	9.6	23.0	58.3	s
Brinjal peel	10.5	12.3	1.6	6.6	26.8	52.7	s
Gram husk	88.4	4.5	5.6	3.2	48.3	38.4	s
Green banana peel	11.7	7.0	6.0	8.8	24.1	54.1	s
Green coconut peel	12.0	4.9	1.8	6.3	30.2	56.8	s
Pea husk	89.2	6.2	2.3	12.6	48.4	30.5	s
Potato peel	16.3	13.0	0.9	9.0	12.5	64.6	s
Pumpkin peel	13.3	16.5	1.9	4.6	14.8	62.2	s
Ripe banana peel	7.7	6.8	7.8	12.1	16.8	56.5	s
Azolla	91.4	21.1	2.5	25.9	14.1	36.3	k,t
Oyster mushroom	12.0	29.1	3.9	11.1	23.7	32.2	u
Leucaena meal	90.1	28.4	5.8	5.5	19.1	41.2	r

Sources: [a]Bhuiyan et al. (2016); [b]Khan et al. (2013); [c]Ahammad et al. (2003); [d]Kawsar et al. (2001); [e]Hossain et al. (2017); [f]Tania et al. (2009); [g]Hossain et al. (2003); [h]Al Mahmud et al. (2012); [j]Hossain et al. (2012); [k]Ali and Leeson (1995); l(Jahan et al., 2013); [m]Hossain and Jauncey (1989); [n]Chowdhury (2001); [o]Khandaker et al. (2007); [p]Sultana et al. (2016); [q]Kabir et al. (2005); [r]Barman and Karim (2007); [s](Hossain et al., 2015); [t]Basak et al. (2002); [u]Ahmed et al. (2013).

Table 13. Proximate percentage composition of major feed ingredients of plant origin in Bangladesh.

Ingredient	Dry matter	Crude protein	Crude lipid	Ash	Crude fiber	NFE	References
Fishmeal	88.67	51.55	6.33	24.42	3.19	14.52	a,b,c
Bone meal	93.75	17.50	5.20	66.35	3.50	7.45	c,d
Shrimp meal	86.00	48.30	5.75	NA	12.90	NA	e
Marine waste	90.00	53.60	6.25	NA	6.50	NA	e
Blood meal	86.05	71.55	0.40	7.50	1.45	38.20	f
Feather meal	51.80	40.60	2.30	3.30	1.30	52.50	f
Leather shavings	88.40	79.80	0.80	8.40	2.30	8.70	f
Hatchery by-product	93.80	37.80	27.30	28.40	0.00	6.50	f
Poultry offal meal	89.75	60.68	20.10	7.45	1.75	10.03	c,f
Earthworm	87.98	27.03	6.04	17.96	NA	NA	g
Crab shell	86.80	25.67	4.25	16.06	NA	NA	g
Fish silage	90.10	56.80	7.50	12.20	6.50	17.00	d
Silkworm pupae	91.60	65.55	15.50	5.00	5.90	8.05	d,f
Snail meal	89.20	53.90	2.80	18.80	1.80	22.70	h

Sources: [a]Al Mahmud et al. (2012); [b]Khan et al. (2013); [c]Hossain et al. (2003); [d]Barman and Karim (2007); [e]Aktar et al. (2012); [f]Tania et al. (2009); [g]Bhuiyan et al. (2016); [h]Ali and Leeson (1995).

Table 14. Proximate percentage composition of major feed ingredients of animal origin in Bangladesh.

used by homemade feed producers. Soybean cake is lower in protein than soybean meal but higher in lipids.

Rape and mustard oil cake

In Bangladesh, the most important oil seed cakes used in aquafeed are rape and mustard oil cakes. Together, these make up 62% of the total number of seed cakes used in the country (Barman and Karim 2007). Domestic production of rape and mustard oil cakes currently stands at 360,000 t, representing no improvement from the previous few years (Indexmundi 2017). Bangladesh is not a net exporter of rape and mustard oil cakes, rather it depends on imports to supplement its local production. In 2016, about 150,000 t of rapeseed meal was imported, especially from India (Indexmundi 2017). The use of rape and mustard oil cakes in aquafeed is exacerbated by competition for its inclusion in other livestock feeds, particularly poultry.

5.4.1.2 Protein sources: Animal origin

Dry fish and fish silage

There is a dearth of data on the volume of fishmeal produced locally in Bangladesh. However, the amounts of fish waste used in aquaculture has been previously estimated to range from 5000 to 70,000 t per year (NACA/FAO 2004). In terms of nutritional value, local fishmeal is generally inferior to the conventional ones produced in countries like Peru and Norway. This is because local fishmeal is manufactured from a combination of items, such as fish waste, crabs and other aquatic animals, which varies from time to time and greatly affects the consistency of the product (Murtuza 1998). However, although it is insufficient to meet the local demand for aquafeed, fishmeal made locally from *chewa* (*Pseudapocryptes elongates*) is of better quality but still not comparable with the conventional fishmeal (Mamun-Ur-Rashid et al. 2013). Aside from its inconsistency and lower nutritional quality, local fishmeal is sometimes intentionally mixed with salt to scale up the weight of the product by as much as 30%–40% (Mamun-Ur-Rashid et al. 2013). This dubious strategy serves as a stumbling block to the effective use of local fishmeal in aquafeed, so attempts should not only be directed at increasing the production and consistency of fishmeal products in Bangladesh, if possible, but substantial efforts should be invested in quality control of locally produced fishmeal.

Shrimp meal

Shrimp production is valuable to the economy of Bangladesh. In 2017, the country earned USD 526 million as foreign exchange from shrimp (BFFEA 2017). Bangladesh ranked sixth based on volume of shrimp production among the world's top producing countries (Rahman and Hossain 2013). About 70–75 million metric tons of shrimp were produced in Bangladesh between 2016 and 2017 (BFFEA 2017). This high production output is usually accompanied by a high quantity of low grade shrimp, which is not good for export but can be used for aquaculture feeding.

5.4.1.3 Energy and fiber sources: Plant origin

Rice and rice by-products

Rice is the most significant crop produced in Bangladesh, so it is unsurprising that the most commonly used feed ingredient in Bangladesh is rice bran. Rice bran, which is about 5% of the total rice yield, is an important component of animal feed. Three common types of rice cultivated in Bangladesh are *Aus*, *Boro* and *Amon*. *Aus* is cultivated in the dry season (May to August), *Boro* is grown in the dry season and harvested before the monsoon season (February to April) and *Amon* is grown during the monsoon season (January to September). This continual production of rice yields a year-round supply of rice bran. Bangladesh rice production output in 2015–2016 was 34 million metric tons (Table 10).

A significant threat to the use of rice bran in aquafeed is the competition with poultry, cattle and buffalo feeds. The quality of rice bran is strongly determined by its fineness (Barman and Karim 2007), which is contingent upon the processing methods. Rice bran produced by automated mills is finer and has a higher available nutrient content compared to those produced through crude husk mills (Barman and Karim 2007). The coarse bran is about a quarter of the price of the finer bran, and the freshness of the bran, the type of rice, storage conditions and duration of storage are factors that determine the quality of the resultant rice bran. Other by-products of interest from rice are broken rice and de-oiled rice bran. Broken rice is damaged low-grade rice, which is unfit for human consumption and sometimes available for animal feeding. De-oiled rice bran is similar to rice bran, but it is a by-product after the extraction of oil from rice bran. The proportion of rice by-products is strongly dependent on the

Photo credit: Agboola JO/WorldFish

A small-scale feed miller in Khulna, Bangladesh.

milling rate, type of rice and other factors. The approximate proportions of rice by-products are 20% hulls, 10% bran, 3% rice polish, 1%–17% broken rice and 50%–60% polished rice (Feedipedia 2017). The proximate composition of rice and its by-products varies greatly and depends on the milling process and the quality of rice (Barman and Karim 2007). Rice polish is readily available in Bangladesh and contains between 5% and 15% crude protein, 1%–18% crude fat and 6%–20% ash (Hossain 2012).

Wheat and wheat by-products

Wheat is another cereal of great importance for both human and animal consumption. In Bangladesh, wheat is mainly known as a *Rabi* season crop, because it requires dry weather and bright sunlight, which are predominant during this period. A large number of farmers in Bangladesh intercrop wheat with rice, and about 1.2 million metric tons of wheat was produced between 2015 and 2016 (Table 10). Wheat flour, a product obtained after milling the wheat, is used mainly for human consumption, though small quantities are also used in pelleted aquafeed (Barman and Karim 2007). Similarly, a small proportion of wheat is also incorporated into the diets of fish fry and prawn immediately after stocking (Barman and Karim 2007). Aside from wheat flour, the most significant by-product of wheat available for animal and aquafeed is wheat bran. Wheat bran as a by-product emanates from dry milling wheat into flour, and it is an important energy source in livestock feed, especially for poultry. The high fiber content of wheat bran reduces its inclusion levels in fish diets. The quality of wheat, the milling process and the analytical methods employed are among the factors responsible for variation in the nutritional content of wheat bran.

Maize and its by-products

Like rice and wheat, maize is another staple food available for human consumption in Bangladesh. Although maize production has grown tremendously over the past couple years, from about 3000 t in 1997–1998 to 64,000 t in 2001–2002 (BBS 2004), the demand for maize for direct incorporation into human food is lower compared to that of rice and wheat. Furthermore, recent data from the Bangladesh Bureau of Statistics (BBS) showed that maize production sustained this upward growth, and that about 2.4 million metric tons of maize was produced within the country between 2015 and 2016 (Table 10). These significant amounts coupled with its low demand for human consumption means there is greater potential for maize's inclusion into animal feeds, particularly for poultry.

The competition for maize as an ingredient in the diet of terrestrial animals rather than for human food is a major constraint to its availability for aquaculture production in Bangladesh. Maize is used as an ingredient in shrimp feed and is a good source of readily digestible carbohydrates (i.e. starch and sugars). Apart from maize meal, other by-products of interest in animal feeds are maize bran and maize gluten, which mainly consists of protein and starch and is produced after removing maize bran and maize steep liquor (Feedipedia, 2017) from maize. Maize bran is the outer covering of the maize.

5.4.2 Potential feed ingredients in Bangladesh

5.4.2.1 Protein sources

Sesame/til oil cake

Sesame meal, also known as til oil cake, is not often used in aquaculture compared with rape and mustard cake. It makes up about 6% of the total seed cakes used for aquafeed in Bangladesh (Barman and Karim 2007). Sesame seed cake is a by-product generated after removing oil from sesame seeds. The nutritional composition varies, but on average sesame seed meal on a dry matter basis contains 32.82% crude protein, 8.13% crude lipids, 13.92% ash, 5.23% crude fiber and 39.9% total carbohydrates (Table 13). The nutritional profiles of this particular feedstuff positioned it as a valuable resource in aquaculture production. Furthermore, sesame oil could also be used to replace fish oil in fish diets. However, the inclusion of sesame oil in fish diets is constrained by its use as cooking oil.

Groundnut cake

Groundnut cake is a by-product that results from carefully removing oil from groundnut seeds. Groundnut seeds are predominantly consumed by humans, but a certain proportion of their by-products could be added into animal diets. Groundnut cakes are usually high in lipids because of the appreciable quantity of oil (more than 10%) remaining in the cakes. About 62,000 t of groundnut seeds were produced in 2016 (BBS 2017). Groundnut contributes 8% to the total fish feed production in Bangladesh (Barman and Karim 2007). Apart from the cakes and oil, another by-product of groundnuts that might be considered in fish diets is groundnut shell. The nutritional profiles of groundnut seeds, cakes and shells are not presented in this report because of a dearth of information in the literature. The biggest challenge to the use of groundnut cake in aquaculture feed is its ease of mycotoxin contamination, particularly aflatoxin. To avoid this, proper oil extraction methods as well as optimum storage condition must be put in place.

Coconut meal

Coconut meal, alternatively known as copra meal, is produced by extracting oil from dry coconut flesh (i.e. copra). Copra meal is important to the aquafeed sector in Bangladesh, as it represents approximately 23% of the total number of seed cakes used in aquaculture production (Barman and Karim 2007). Approximately 360,000 t of coconut was manufactured in 2016 (BBS 2017). The nutritional composition of coconut meal varies depending on the type/source of coconuts and various parameters used during the oil extraction process. A typical coconut meal manufactured in Bangladesh contains 18.82% crude protein, 11.66% crude lipids and 7.26% ash (Table 13).

Blood meal

Copious quantities of chicken, cattle and especially ram during the Muslim festival are slaughtered annually in Bangladesh. Bangladeshis, largely Muslims, are known for their strong appetite for beef, and slaughtering cattle generally generates large amounts of blood, which can be processed and used as feed resources. Blood is a rich source of protein, containing 70% or more crude protein. However, its high moisture content is one major constraint affecting its processing into animal feed. Instead, blood is usually mixed with other feedstuffs, such as rice bran or wheat bran, to serve as an absorbent before drying. Another major drawback is the fact that blood contains a plethora of pathogens that can cause a myriad of diseases when fed to fish or other livestock animals, so it is preferable to process and dry blood into meal before using it.

5.4.2.2 Other nutrient sources

Khesari seed

Khesari seed (*Lathyrus sativus*) is a leguminous crop that is highly nutritious. It is known as an "insurance crop" because of its ability to thrive even in extreme weather conditions when all other crops fail. The seed is commonly grown for human and animal consumption in Asia and some parts of Africa. In Bangladesh, approximately 122,000 t of Khesari seeds were produced in 2016, and they were among the largest group of pulses cultivated in Bangladesh (BBS 2017). The average nutritional values of this particular seed are as follows: 26.73% crude protein, 2.56% crude lipids, 5.04% ash, 4.96% crude fiber and 60.70% of total carbohydrates (Table 13). Despite these nutritional components and the potential capability of khesari seed as a feedstuff in aquafeed, the presence of a neurotoxin that causes neurodegenerative diseases when fed for a prolonged period of time is one major drawback mitigating its inclusion in aquafeed.

Potato peel

Potato is extensively cultivated yearly in Bangladesh. In 2016, 9.5 million metric tons of potatoes were produced in the country for human use (Table 13). However, because of a lack of proper and sophisticated storage facilities, several metric tons of potatoes are usually dumped every year (Sultana et al. 2016), which causes environmental problems. To prevent this, strategies such as including potatoes into poultry diets have previously been explored (Sultana et al. 2016). This area of research should extend to aquaculture to examine the possibility of incorporating unused potatoes into the diets of fish. Furthermore, potato peels, which are a by-product of potatoes, are usually discarded. Instead, they can be used in feeding animals and could also be effectively incorporated into the diets of various fish species because they contain high amounts of nutrients: 13% crude protein, 0.9% crude fat, 9% ash, 12.5% crude fiber and 64.6% total carbohydrates (Table 13).

Cassava peel and leaf

Although Bangladesh is not a top producer of cassava in the world, it has the potential to increase its annual production. The volume of cassava currently being used around the country (mainly for industrial and bakery purposes) is substantial (Afreen and Haque 2014), though data on the production and use of cassava in Bangladesh is lacking. Few private firms do actively engage in its cultivation by employing farmers on contract basis (Afreen and Haque 2014). Cassava is predominantly cultivated as a source of starch for human consumption and is also a valuable raw material for industrial starch production. However, substantial amounts of by-products, in the form of leaves and peels, are constantly churned out during the conversion of cassava to finished products. These by-products are highly nutritious and contain an appreciable quantity of nutrients, particularly starch, that could be used for animal consumption. These by-products could also be included in aquaculture diets. The nutritional constituents of the different by-products vary greatly from each other, and it appears that cassava leaf meal is more nutritionally dense compared to cassava peel (Table 13). Of the immense benefits associated with cassava and its by-products, the major drawback to its effective use in animal feed is the presence of hydrogen cyanide and the ease of mycotoxin (aflatoxin) contamination.

Banana peel and leaf
Banana is one of the most important fruit crops cultivated in Bangladesh, with about 790,000 t produced in 2016 (Table 10). However, only 568 t of banana, valued at USD 655,000, were exported in 2013 (FAOSTAT), which indicates that most of the banana produced in Bangladesh is consumed locally. The consumption and use of banana are usually accompanied by substantial quantities of by-products in form of peels, which are suitable for animal feed, particularly ruminant animals. These peels make up about 30% of the total banana production and are usually left scattered around the country. The ripeness of the peels affects the nutritional composition. Ripe peels have varying nutritional components compared to unripe peels. Ripe peels have less crude fiber compared to unripe peels (Table 13). These peels can be fed fresh (as in the case of ruminants) or dried (either by sun or any other methods) and converted into chips or other forms before being included into animal feeds. Other by-products of interest from banana are banana leaves, which can be processed after drying into banana leaf meal and be included in aquafeed.

Pineapple by-products
Pineapple is another important fruit for Bangladesh, which produced about 7.2 million metric tons in 2016 (BBS 2017). Pineapple is most often used by humans, especially the pineapple cannery industry. Postharvest processing of fruits usually generates large amounts of by-products, such as skins, crowns and pomace (after juice extraction), which are indiscriminately disposed of into lands and water bodies. To curb the environment degradation caused by these by-products, they could instead be incorporated into livestock feeds. Pineapple waste can be fed fresh to ruminants, and also to poultry and fish as bran after drying. However, the high moisture content of pineapple waste restricts its use in animal diets, and the low crude protein content of the waste (4%–8%) means that it must be supplemented with other protein sources to prevent detrimental effects on animal productivity and health (Wadhwa and Bakshi 2013).

Mango kernels and peels
Bangladesh is ranked ninth in global mango production. The country produced 1.2 million metric tons of mango in 2016 (Table 10), but only 308 t, worth about USD 556,000, were exported in 2013 (FAOSTAT). This means the current foreign earnings from mango are presumably above what was generated in the previous years. Nevertheless, large amounts of mangoes are currently processed in Bangladesh. In fact, mango is the most common fruit item processed in the country, for both local consumption and export to international markets (BIDA 2016). Gooty and Ashina are the two major mango categories processed in Bangladesh, and about 100,000 t of these varieties are processed annually (BIDA 2016). Mango kernels and peels are the main by-products from mango and represent about 30%–60% of the total weight of the fruit, depending on the cultivars and mango products made (Jahurul et al. 2015). Bangladesh therefore produced an appreciable quantity of mango by-products that could be processed and used in aquafeed. There is paucity of information on the nutritional quality of these by-products, so relevant data in that regard is not presented in this report.

Sugarcane by-products
Sugar production has a long history in Bangladesh and invariably serves as a means of generating employment and earning foreign exchange. Over time, this industry has grown exponentially and likewise the quantity of sugarcane production in the country. In 2016, 4.2 million metric tons of sugarcane were produced in Bangladesh, half of which went to sugar mills while the other half was used in molasses production (Table 10). Although molasses requires supplementation with other ingredients, it can be included in aquafeed and is known to contain significant amounts of sugar. Aside from this, other by-products of interest from sugarcane are bagasse and press mud, which are generated after extracting sugars and could

be considered as ingredients for aquaculture. Furthermore, other residues of less commercial values, such as trash, green tops, wax, fly ash and spent wash could also be examined as aquaculture feedstuff. Despite the enormous amounts of by-products generated by the sugarcane industry, their inclusion in aquafeed is restricted by the consumption/use by humans, their high fiber content, which makes them less digestible for fish, and their imbalanced nutrient contents, especially their low protein values.

5.4.3 Nonconventional feed resources present in small amounts

Nonconventional materials such as drumstick leaf meal, azolla, duckweed, brinjal peel, pumpkin peel, coconut peel, leucana meal and pea husk are available in Bangladesh and could be considered aquaculture feed resources. Likewise, other nonconventional feed resources of animal origin (though mostly limited in quantities) are marine waste, feather meal, leather shavings, hatchery by-products, poultry offal meal, crab shell meal and snail meal. In addition, earthworm and silkworm pupae are other alternative feed ingredients that can be used in Bangladesh.

5.4.4 Priority aquafeed ingredients for further research in Bangladesh

Ingredients that should be given priority for further research in Bangladesh are summarized in Table 15. This information contains both current and potential ingredients that are domestically produced in Bangladesh and/or sourced from neighboring countries.

5.4.5 Conclusions for Bangladesh

Aquafeed production in Bangladesh depends on the use of imported fishmeal as protein, especially for commercial feed producers. In contrast, small-scale feed producers use dry fish, which are mainly sourced domestically and have a lower nutritional quality than imported fishmeal. The nutritional quality of dry fish can be improved through improved processing methods, unlike sun drying and grinding, which local dry fishmeal producers currently use. Shrimp meal, blood

Marketing fish at the fish market in Khulna District.

Ingredient	Research action(s)
Protein sources	
Soybean cake	• Improve processing methods to increase the protein content of locally produced soybean cake.
Mustard oil cake	• Improve processing methods to increase the protein content of locally produced mustard oil cake and also to reduce its vulnerability to mycotoxin contamination.
Sesame cake	• Further information needed on the amount available in the country.
Groundnut cake	• Further information needed on the amount available in the country.
Copra meal	• Further information needed on the amount available in the country.
Dry fish	• Improve processing methods to increase the protein content of locally produced dry fish and also to reduce dustiness.
Shrimp meal	• Improve the logistics surrounding the availability of shrimp so that quality shrimp is available for shrimp meal processing. • Improve processing methods to increase the protein content of locally produced shrimp meal.
Blood meal	• Improve collection and processing methods to increase the availability of feather meal for aquafeed production.
Feather meal	• Improve collection and processing methods to increase the availability of feather meal for aquafeed production.
Energy sources	
Maize	• Replace with quality alternatives that have less or little competition from humans and livestock.
Wheat bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Wheat flour	• Increase the inclusion level through appropriate research without compromising fish growth.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Rice polish	• Further information needed about the amount available in the country • Increase the inclusion level through appropriate research without compromising fish growth.
Potato peel	• Further information needed about the amount available in the country.
Khesari seeds	• Improve processing methods to decrease the level of fiber in khesari seeds meal.
Broken rice	• Further information needed about the amount available in the country.
Cassava peel	• Further information needed about the amount available in the country.
Rice polishing	• Further information needed about the amount available in the country.

Table 15. Priority ingredients to consider for aquafeed and proposed research to improve their nutritional quality.

meal and feather meal are other animal protein sources that could be included in aquafeed. Shrimp meal is abundantly available, though the actual amount is unknown, but there is a need to increase its protein content through the use of improved processing techniques, such as that used in making high quality fishmeal. In addition, collecting and processing feather and blood need to be well organized. Blood and feathers coming from the livestock sector are currently not use. These could be collected in bulk and processed into high quality protein ingredients for aquafeed. Soybean cake and mustard cake are the two most important locally available protein sources of plant origin. Others plant ingredients for future consideration are sesame meal, groundnut cake and copra meal. The vast majority of energy ingredients are sourced locally. The most common energy ingredients in Bangladesh are maize, rice bran, wheat flour, wheat bran and, to some extent, khesari seeds and broken rice. Future research should focus on the use of potato peel and cassava peel as energy ingredients for aquafeed in Bangladesh. Moreover, it could take into consideration the use of novel ingredients, such as azolla, duckweed, banana by-products and mango by-products, as aquafeed ingredients in Bangladesh.

Fish feed manufacturer being interviewed in Khulna, Bangladesh.

6. Country review: Myanmar

6.1 Introduction

Myanmar has a population of 56,890,418 and a total land area of about 676,576 km^2. The country's administrative divisions consist of seven regions, seven states and one union territory (Figure 10). It has vast water bodies, which are essential for supporting the rise of aquaculture in the country. These water bodies include inland waters, which are composed of mingling riverine and estuarine systems of the Irrawaddy (2150 km long), Chindwin (844 km long), Sittaung (633 km long) and Thalwin (2400 km long) rivers, as well as a small section of the Mekong river basin (van der Pijl and van Duijn 2012). GDP is estimated at USD 307.3 billion, of which 40% is contributed by the agriculture and seafood sectors (Indexmundi, 2017). These two sectors account for about 70% of the entire labor force. The main export commodities are natural gas, wood products, pulses, beans, rice, fish, clothing, jade and gems (van der Pijl and van Duijn 2012).

Figure 10. Administrative divisions of Myanmar.[3]

6.2 Aquaculture in Myanmar

The expansion of aquaculture in Myanmar started around 1988 and has increased on average about a 40% per year (Ng et al. 2007). Aquaculture represents about 34% of the total fisheries sector production (DOF 2015). Aquaculture is predominantly conducted in ponds and covers a total area of 181,000 ha consisting of about 92,000 ha under shrimp culture and 89,000 ha under fish culture (van der Pijl and van Duijn 2012). The shrimp and freshwater prawn aquaculture subsector has almost collapsed because of disease outbreaks (Michael Akester, personal communication, 2018). White-legged shrimp (*Litopenaeus vannamei*) is also being produced in small but increasing quantities (Michael Akester, personal communication, 2018). Freshwater fish species such as carp, tilapia, catfish and freshwater prawn (*Macrobrachium rosenbergii*) are commonly cultivated. Polyculture is the popular system of cultivation, with Chinese and Indian carp cultured together, and tilapia with *Pangasianodon* catfish. Monocultures of tilapia, catfish and freshwater prawn are gaining increasing attention (Ng et al. 2007). Ponds for polyculture are usually large and range from 4 to 8 ha (Ng et al. 2007). Although, there are some larger commercial farms, the sector is dominated by small-scale producers. Table 16 shows Myanmar's aquaculture production per species in 2015.

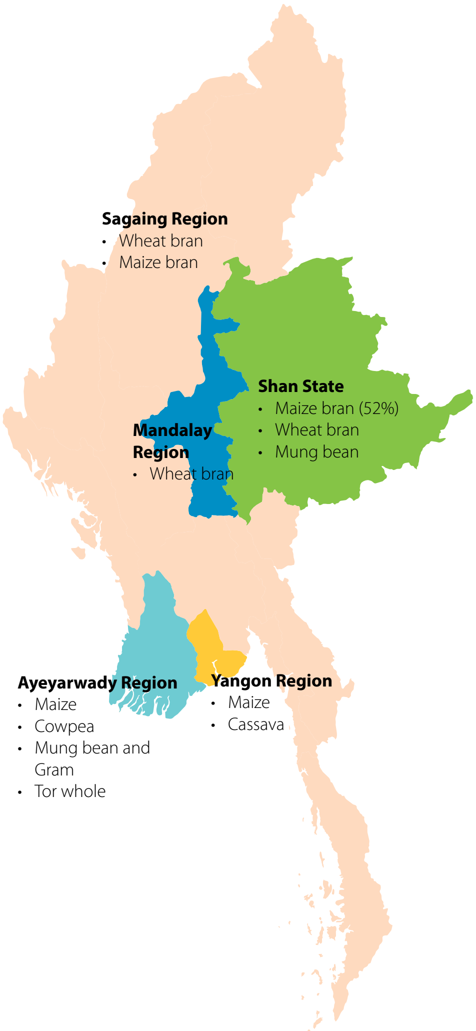
6.3 Status of Myanmar aquafeed industry

Myanmar is an agricultural country producing different crops (Table 17 and Figure 11). These agricultural products are largely meant for human consumption. However, they are often accompanied by large amounts of by-products, either from the field or during processing, which could be used as animal feed. Before 1990, farmed fish were fed exclusively farm-made feeds made up of ingredients such as broken rice, groundnut cake and rice bran (1:2:7), which were cooked in large woks and fed to fish as moist mash (Ng et al. 2007). This is done by placing the combination of rice bran and groundnut cake (5:1) in feeding bags (made from mosquito netting) and putting them

Species	Quantity (t)
Rohu labeo	619,500
Mrigal carp	69,200
Catla	64,500
Giant tiger prawn	49,900
Pangas catfish	41,500
Tilapia	32,300
Pirapatinga	27,700
Common carp	18,400
Torpedo-shaped catfish	13,800
Grass carp (white amur)	13,800
Bighead carp	12,000
Silver carp	11,100
Silver barb	10,600
Freshwater fish	7,400
Orange mud crab	2,800
Giant river prawn	2,300
Barramundi (giant seaperch)	500

Source: FishStatJ 2017.

Table 16. Aquaculture production per species in Myanmar (2015).



Ubiquitous
- Rice bran
- Broken rice
- Sesame
- Groundnut
- Peanut cake
- Sunflower cake

Source: editable map from: yourfreetemplates.com.

Figure 11. Crop distribution based on the different administrative divisions of Myanmar.

Ingredient	Production (t)	By-products
Rice paddy	24,718,000	Rice bran, broken rice
Chickpea	3,574,000	Bran, straw, pod husks
Peanut/groundnut oil seed	1,039,000	Groundnut cake
Black gram	899,000	Bran
Maize	784,000	Broken maize, maize meal
Mung bean (green gram)	778,000	Bran
Toor whole (pigeon pea)	547,000	Pigeon pea reject
Sesame	539,000	Sesame seed cake
Sunflower	385,000	Sunflower seed cake
Cotton	195,000	Cotton seed meal
Soybean	165,000	Soybean cake
Cowpea	130,000	Cowpea seed waste, hulls
Wheat	124,000	Bran

Source: Ng 2007; Indexmundi 2017.

Table 17. Total production of agriculture crops in Myanmar (2004–2005).

directly into ponds (Ng et al. 2007). The majority of small-scale farmers are still currently using farm-made feeds to feed their fish (Ng et al. 2007). About 25% of farmers are using commercial feeds while the remaining 75% use locally available rice bran only or rice bran with oil cakes.[4]

There are over 20 feed mills, out of which 11 are producing floating pellets and three manufacturing sinking pellets.[3] The production capacity of local feed mills ranges from 100 to 250 t per day.[3] In Myanmar, the vast majority of feed resources used for both farm-made and commercial feeds are sourced locally. These include rice bran, groundnut cakes, sesame seed meal, dried marine fish, shrimp meal, fishmeal and fish oil. Despite this apparent self-sufficiency in feed ingredients, the development of aquaculture in Myanmar is generally hampered by (1) inadequate research on the nutritional composition of feedstuff and the feeding requirements of the major culture species, (2) a lack of sufficient analytical laboratory, and (3) poor aquafeed manufacturing practices, which always result in the production of mycotoxin-contaminated feeds.

6.4 Available feed resources in Myanmar

In this section, information on the current feedstuffs and those with potential to be incorporated into aquafeed are highlighted in Table 18. There is a dearth of literature on the proximate composition of the available ingredients in Myanmar. However, data from Obara et al. (1974) on analyses conducted for some of these ingredients is summarized in Table 19. This lack of information could be attributed to inadequate research on the nutritive values of available feed resources within the country or that the available literature is in Burmese.

6.4.1 Protein and oil sources: Plant origin

Groundnut (peanut) cake and oil

Groundnut, also known as peanut, is one of the major oil crops cultivated in Myanmar. It is mainly cultivated in the central dry zone of the country as both a monsoon and late monsoon season crop. It is an important edible crop grown for food and as a cash crop. Groundnuts are grown on about 700,000 ha (Shwe and Kyu 2017). Recently, there has been improvement in the production of groundnut oil

Photo credit: Agboola J.O/WorldFish

Small-scale cage culture in the Irrawaddy Delta, Myanmar.

Ingredient	Currently used in aquafeeds	Source
Blood meal	No	Local
Broken rice	No	Local
Cowpea	No	Local
Fishmeal	Yes	Imported
Gram	No	Local
Gram meal	No	Local
Gram dust	No	Local
Gram husk	No	Local
Groundnut cake	Yes	Local
Maize	Yes	Local
Paddy	No	Local
Pigeon pea	No	Local
Prawn meal	No	Local
Rice bran	Yes	Local
Sesame cake	Yes	Local
Wheat bran	No	Local
Dry fish	Yes	Local
Soybean meal	Yes	Imported
Soybean cake	Yes	Local
Feather meal	Yes	Imported/local
Squid meal	No	Local
Poultry meal	Yes	Imported
Sunflower seed meal	No	Local
Cotton seed meal	No	Local

Table 18. Available ingredients for aquafeed production in Myanmar.

Ingredient	Dry matter	CP	Fat	Fiber	Ash	NFE	Ca	P
Blood meal	90.98	62.3	1.95	1.68	2.7	31.37	0.076	0.049
Broken rice	91.81	8.68	3.28	0.97	1.33	85.74	0.077	0.255
Cowpea	91.85	23.85	5.49	5.91	4.67	60.08	0.282	0.199
Fishmeal	86.19	56.3	7.09	0.52	22.83	13.26	5.62	2.22
Gram	90.61	18.88	6.9	13.46	3.92	56.84	0.256	0.03
Gram meal	91.48	18.59	7.32	16.81	6.95	50.33	0.356	0.312
Gram dust	90.65	11.54	4.74	33.73	3.9	46.09	0.741	0.21
Gram husk	91.56	3.32	2.15	46.81	3.81	43.91	0.872	0.035
Groundnut cake	92.18	45.08	5.76	7.65	7.14	34.37	0.221	0.573
Maize	91.06	9.28	6.77	2.11	1.78	80.06	0.115	0.337
Paddy	91.43	6.98	5.94	11.23	6.86	68.99	0.064	0.205
Pigeon pea	91.49	19.91	4.6	5.77	3.86	65.86	0.177	0.13
Prawn meal	88.41	36.14	4.54	7.18	38.92	13.22	4.75	0.595
Rice bran	91.18	11.76	16.3	7.78	9.13	55.03	0.143	1.093
Sesame cake	93.38	39.94	10.66	8.32	20.28	20.8	1.7	1.39
Wheat bran	87.44	16.64	6.38	7.84	4.82	64.32	0.163	0.81

Source: Obara et al. 1974.

Table 19. Percentage nutritional composition of available ingredients in Myanmar.

seeds in Myanmar, from about 900,000 produced in 2003 to 1.4 million t in 2017 (Indexmundi 2017), and the country is now the sixth-largest producer of this crop in the world. Groundnut seeds (without the pod) contain 42%–56% oil. The seeds are principally used for oil extraction, so groundnut meal is readily available within the country. Groundnut meal is an excellent feed ingredient because it is high in protein, low fiber and high in oil (depending on the extraction methods), and there is a relative absence of antinutritional factors (Table 19). The biggest dilemma, aside from competition with other livestock sectors, to the availability of groundnut meal for aquafeed, is its ease of aflatoxin contamination. Unfortunately, this occurs quite commonly in Myanmar because of the crude methods of oil extraction and improper storage of the meal.

Sesame cake, oil and hulls

Myanmar is the world's third-largest producer of sesame, at 7% of worldwide production (Favre and Myint 2009). Sesame is the most extensive and widely cultivated oil seed crop in Myanmar. It accounts for 44% of the total oil crop area, covering 3.31 million acres (Favre and Myint 2009). In 2005, there were 500,000 t of sesame seeds produced in Myanmar (Table 17). Sesame meal, a protein-rich by-product of oil extraction, can be incorporated into aquafeed. The quality of the sesame meal depends on the extraction methods adopted. Aside from this, the hulls left over from de-hulling can also be considered as ingredients in fish diets. Sesame oil, although chiefly meant for human consumption, is another by-product that can be incorporated into aquafeed, especially to replace fish oil, which is currently being used in Myanmar.

Sunflower seed meal and oil

Another important oil seed cultivated in Myanmar is sunflower. It is the third-most important oil seed in the country, though the cultivation of this

Photo credit: Agtech/WorldFish

Salting and sun drying of snakeskin gurami as a value addition process in the Irrawaddy Delta, Myanmar.

crop compared to previous years has declined significantly. The current production has dropped from 385,000 t in 2005 (Table 17) to about 160,000 t today (Indexmundi 2017). It contributes 12% to the indigenous oil production (Favre and Myint 2009). Sunflower seed meal and oil are valuable feed resources that can be used to supply the required nutrients to fish.

Soybean meal and oil
Over 20 varieties of soybean are cultivated in Myanmar (Favre and Myint 2009). The Department of Agricultural Research in Myanmar is responsible for improving the quantity of soybean produced within the country through aggressively developing improved local varieties. These efforts could yield no or little positive results as the amount of soybean currently produced in Myanmar (based on Indexmundi) is more or less the same as that produced about 10 years ago (Table 17). Nevertheless, soybean meal and soy oil can be explored as feed resources for aquaculture production in Myanmar.

6.4.2 Protein and oil sources: Animal origin

Fishmeal and fish oil
In 2011, there were 36,423 t of fishmeal produced from discarded fish (Kyaw 2015). However, the rapid development of aquaculture in Myanmar implies that continuous dependency on fishmeal from fish bycatch will become unsustainable in the near future, so alternative feed resources, particularly of animal origin, are needed. Nevertheless, there is a need to continuously use discarded fish generated in the country in the most sustainable way. This can be done by improving the fishmeal production process to derive maximum benefits from the product. This would ensure that the fishmeal produced will be on par with that produced in other parts of the world, such as Peru and Denmark. In addition, although it is less nutritious, dry fish, which is generally produced from fish not fit for human consumption, is used in aquafeed (Kyaw 2015).

Blood meal
Myanmar's total meat production, encompassing both beef and chicken, was 3000 t in 2016 (LBVD). Ultimately, this generates substantial amounts of blood that could be recycled back into aquafeed. Blood meal is a by-product from abattoirs, especially from slaughtering poultry and cattle. The blood is wasted and often causes environmental problems if not properly managed, but when harnessed it can be a valuable protein source. To the author's awareness, this particular resource remains untapped in Myanmar.

Shrimp shell and head meal
In Myanmar, shrimp shell and head meal are the main marine fish ingredients (Kyaw 2015). These are usually derived from giant tiger shrimp (*panaeus monodon*), which is widely cultivated in the country. The shell and head are mostly unfit for human consumption, so they are available as feed ingredients. About 10% of shrimp shells and heads are used to feed carnivorous species, which is considerably higher than the 2%–3% incorporated into freshwater fish feeds.

Squid meal and oil
Squids are cephalopods that are produced in large quantities in Myanmar, mostly for human consumption. These are often available in excess of human demand and therefore can be processed into squid meal and oil that can be reused as feed ingredients.

6.4.3 Energy and fiber sources: Plant origin

Rice bran and broken rice
Rice production and cultivation is common in Myanmar. In 2004, 25 million metric tons of rice were cultivated, so it is conceivable to have large volumes of by-product (Table 17). Rice production occurs within every region in the country. Two of the dominant by-products for aquafeed are rice bran and broken rice. Considering rice bran makes up 10%–30% of the total rice production, it can be assumed that approximately 2.5 million metric tons of rice bran were manufactured in 2004. Rice bran and boiled broken rice are used as energy sources in aquafeed. For every 1 kg of fish, about 4–5 kg of rice bran is needed, so the feed conversion ratio (FCR) is usually 4–5, depending on the quality and type of rice (Kyaw 2015). This relatively high FCR means rice bran or broken rice should be fed in combination with other ingredients to meet the dietary requirements of fish.

Maize
Maize is another staple food produced in Myanmar. Currently, 2.2 million metric tons of maize are produced in Myanmar, of which 1 million metric tons are consumed domestically (Indexmundi 2017),

so there is greater avenue to use maize and its by-products (maize bran and maize meal) in aquafeed. Maize is an energy ingredient that can be combined with other protein-rich feedstuffs for fish production. The proximate composition of typical maize produced in Myanmar is listed in Table 19. Maize meal, which is ground dried maize, can be mixed with ingredients such as groundnut cake, sesame meal and additives to supply essential nutrients for fish. Maize bran, on the other hand, is a by-product of various maize processing industries, including starch and ethanol production (Feedipedia 2017). Maize bran refers to the bran coating removed during the early stages of the processing, and the maize bran sold for animal feeding is usually a mixture of the bran and other by-products generated during the later stages of the processing (Feedipedia 2017). The central part of the country, particularly Shan State, is largely responsible (52%) for the total maize production in the country (USDA 2015).

Wheat bran

Wheat is produced at subsistence level because of the limited area suitable for wheat cultivation and the lower economic returns compared to other crops. As a result, wheat is primarily cultivated for animal feed (USDA 2015). Approximately 170,000 t of wheat were produced in 2016 (Indexmundi 2017), mostly in the northwest, eastern and central parts of the country (USDA 2015). Apart from whole wheat, other potential wheat by-products for aquafeed include wheat bran and wheat straw.

Wheat bran, a by-product of dry milling wheat, can be incorporated into animal feed as an energy source. The nutritional composition of wheat bran is outlined in Table 19.

Gram by-products

A wide range of pulses are cultivated in Myanmar, including green and black gram. Gram seeds are common staple foods widely consumed in South Asia. They can be ground into powder and used in local breadmaking. About 899,000 and 778,000 t of black gram and mung bean were produced within the country in 2005 (Table 17). Gram residues (co-product locally known as *chunies*), make up 15%–20% of the seed weight and comprise mainly the hulls, with little addition from germs and broken seeds (Feedipidia 2016). Based on this data, between 134,850 and 179,800 t of gram *chunies* were produced in 2005. The seeds are generally too expensive to be used as animal feed, but the gram *chunies* offer great potential. Apart from this, other by-products from gram seeds that can serve as ingredients for aquafeed are indicated in Table 19. Gram has considerable amounts of protein, fats, total carbohydrates and starch, so it can be mixed with other feedstuffs to meet the nutritional requirements of different fish species. To lower the price of gram and increase its availability for animal feed, production must be significantly increased throughout the country. This would ensure year-round availability of gram for both human and animal consumption.

Photo credit: Agboola J.O./WorldFish

Squid up for sale at the San Pya fish market in Yangon, Myanmar.

6.4.4 Priority aquafeed ingredients for further research in Myanmar

Table 20 lists ingredients of interest for further research as aquafeed ingredients in Myanmar. The ingredients are locally produced and could substantially decrease the costs of aquafeeds in the country.

6.4.5 Conclusions for Myanmar

Groundnut cake is predominantly used as a plant protein source for aquafeed production in Myanmar. However, production is limited by its sensitivity to mycotoxin contamination, so efforts should be directed at improving the processing and storage methods to reduce the levels of mycotoxin (particularly aflatoxin) present in locally produced groundnut cake.

Aside from groundnut cake, other plant protein ingredients that could potentially be used in aquafeed production are soybean cake, sesame cake, sunflower seed meal, cotton seed meal and gram meal, but the current production volume of these oil seeds is unknown. Further efforts should be geared toward determining their availability for aquafeed production. Dry fish made from discarded fish is available within the country, but its nutritional content is lower than that of conventional fishmeal. Blood meal, squid meal, feather meal, poultry meal and shrimp meal are other animal protein sources with promising prospects as aquafeed ingredients. Maize bran, rice bran, maize meal and gram bran are commonly available energy sources for fish feed production. Additionally, future research in Myanmar should equally consider the prospects of using novel feeds ingredients, such as insects, algae (both micro-algae and macro-algae), bacterial biomass, etc., in fish feeds.

Ingredients	Research action(s) needed
Protein sources	
Soybean cake	• Further information needed on the volume of soybean seeds produced within the country. • Improve processing methods to increase the protein content of locally produced soybean cake.
Groundnut cake	• Improve processing methods to increase the protein content of locally produced mustard oil cake. • Improve processing methods to produce high quality groundnut cake with decreased mycotoxin contamination.
Sesame cake	• Further information needed on the volume available within the country.
Sunflower seed meal	• Further information needed on the available volume of sunflower seed meal for aquafeed production.
Cotton seed meal	• Further information needed on the available volume of cotton seed meal for aquafeed production.
Gram meal	• Further information needed on the volume available within the country.
Dry fish	• Improve processing methods to increase the protein content of locally produced dry fish for aquafeed production.
Blood meal	• Improve collection and processing methods to increase availability of blood meal for aquafeeds.
Feather meal	• Improve collection and processing methods to increase availability of feather meal for aquafeeds.
Squid meal	• Further information needed on the volume of squid available for squid meal production.
Poultry meal	• Further information needed on the available volume of poultry offal for poultry meal production.
Prawn/shrimp meal	• Further information needed on the volume available within the country.
Energy sources	
Maize meal	• Replace with quality alternatives, with less or little competition from humans and livestock.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Maize bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Gram bran	• Further information needed on the quantities available for aquafeed production.

Table 20. Priority ingredients to be considered for aquafeeds, with proposed further research to improve their nutritional quality.

7. Country review: Malaysia

7.1 Introduction

Malaysia is divided into two main regions—Peninsular Malaysia, which is situated on the Malay Peninsula, and the Malaysia Borneo, situated on the island of Borneo—that are distinctively separated by the South China Sea (Figure 12). Malaysia has 13 states and three federal territories and has a total area of 329,847 km^2. Domestic consumption is the major driver of the economy, accounting for 53% of GDP.[5] The dwindling price of oil in the global market downregulated government revenues from the oil and gas sector in 2015 compared to previous years.[6] However, agriculture has been the mainstay of the economy and contributed 11% to total GDP in 2012 (Rahman 2012). Malaysia is the largest exporter of palm oil in the world. The country exported 16.5 million metric tons out of the 18.8 million metric tons it manufactured in 2016 (Indexmundi 2017). Aside from revenue generation through exports and local consumption of palm oil and palm oil-derived products, Malaysia is well known as a fish-consuming country, with fish accounting for 60% of total animal protein intake (Liong et al. 1988).

7.2 Aquaculture in Malaysia

Aquaculture started in Malaysia in the 1900s with the culture of Chinese carps in mining pools (Liong et al. 1988). Since then, the sector has improved considerably over the years. Table 21 depicts the contribution of each species to total aquaculture production for 2007. Major freshwater species farmed are tilapia, catfish and carp. Red hybrid tilapia makes up 82% of total tilapia production (Ng 2009). Blood cockle (*Anadara granosa*) is cultivated in large quantities, amounting to 18% of total aquaculture production (Ng 2009), while white shrimp (*Panaeus vannamei*) and black tiger shrimp (*P. monodon*) make up 80% and 20% of total shrimp production, respectively. Ornamental fish and aquatic plants contributed MYR 825 million (~USD 206.25 million) in 2007 (Ng 2009). Cyprinids (goldfish, koi, barbs, danios) and poecilids (guppies, mollies, platies) accounted for 21% and 23% of total ornamental fish production, respectively (Ng 2009). Aquaculture production doubled from 268,000 t in 2007 (Ng 2009) to 506, 000 t in 2015 (FAO 2017). However, Malaysia still has considerable potential for aquaculture

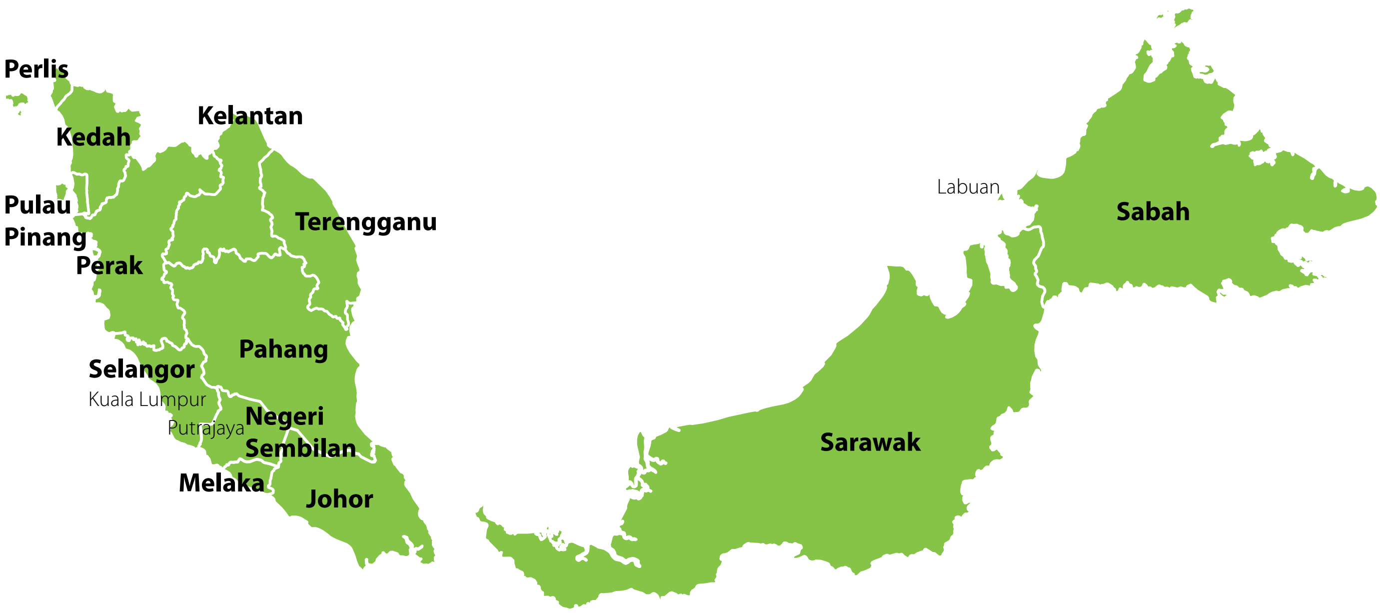


Figure 12. States in Malaysia.[6]

development in the forseeable future. Favorable government policies, new technologies (fish breeds and feeds), increased investments and the presence of vast bodies of water in both West and East Malaysia strongly support this assumption.

7.3 Status of aquafeed industry

In Malaysia, the intensive livestock industry is overly dependent on imported feedstuffs. These ingredients vary greatly and include cereal grains, vegetables and animal proteins, including soybean meal, maize gluten meal, fishmeal, meat and bone meal, mineral sources, micro-ingredients and additives (Loh 2004). On the other hand, the main crop residues and agro-industrial by-products, such as palm kernel cake, rice bran, sago, broken rice, tapioca and coconut cake, are all used in the ruminant industry (Loh 2004). Local feed resources and their availability are presented in Table 22, and the distribution of these feed resources is shown in Figure 13. According to Raghavan (2000), there were 43 compound feed companies in West and East Malaysia, ranging from small- to medium- to large-scale operations, which produce nearly 4 million metric tons of feed annually. In addition, home-mixers cater to 275,000 t of feed per annum (Raghavan 2000).

An overview of the aquafeed industry in Malaysia is presented in Box 1.

7.4 Available feed resources in Malaysia

7.4.1 Protein sources: Plant origin

Soybean meal

Local production is insufficient to meet the local demand of soybean meal in Malaysia. In 2016, 75% or more of soybean meal consumed was imported (Indexmundi 2017). Approximately 465,000 t of soybean meal were produced and 1.5 million metric tons were imported into Malaysia in 2016 (Indexmundi 2017), an increase from the amounts of soybean meal required and imported in 2000, though local production remained more or less the same (Figure 14). Locally generated soybean meal is nutritionally inferior compared to imported soybean meal. Its nutritional contents range from 25%–40% crude protein, 1%–2% crude fats, 6%–7% ash, 10%–11% crude fiber and 40%–45% nitrogen-free extract (NFE). Since enormous amounts of soybean meal are imported

Species type	Production (t)	% total production	Major species	% in each type
1. Freshwater	70,000	26	Tilapia	46
			Catfish	42
			Carp	7
			Snakehead	1
			Other	4
2. Marine and brackish water	151,000	56	Blood cockle	33
			Shrimp	23
			Sea bass	4
			Grouper	3
			Snapper	3
			Seaweed	28
			Other	6
2a. Shrimp	34,000	12	White shrimp	80
			Black tiger shrimp	20

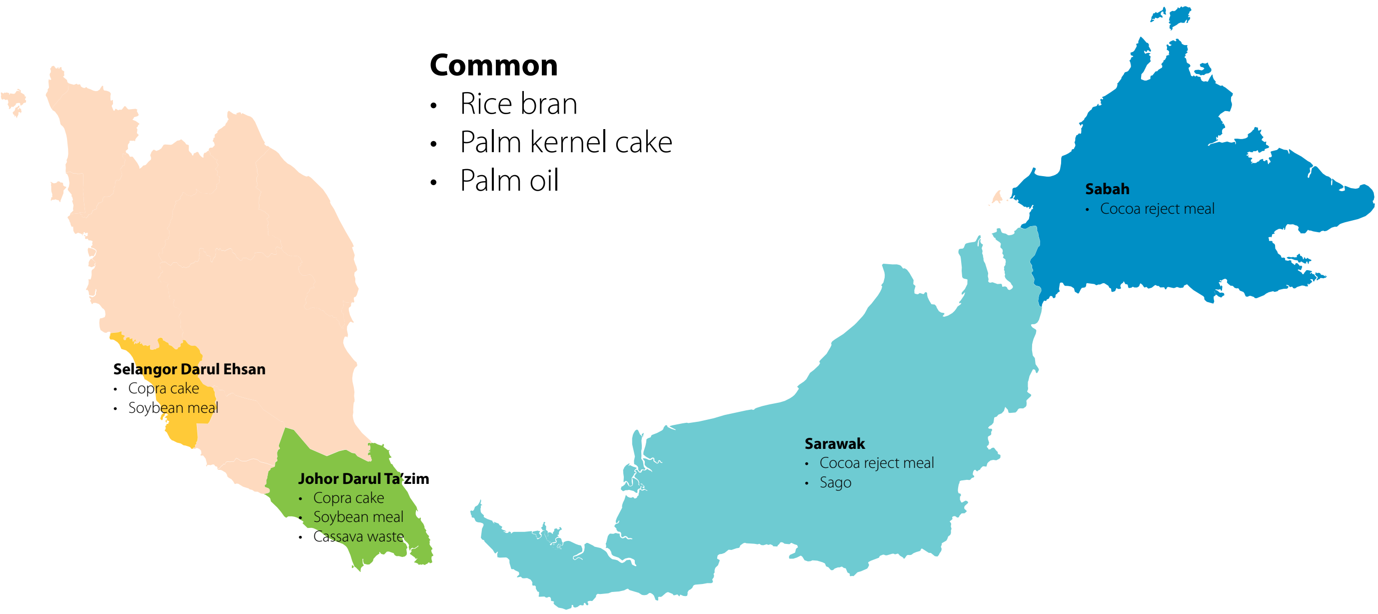
Source: Ng 2009.

Table 21. Species contribution to total aquaculture production in Malaysia.

Ingredient	Yield (t)	Availability
Palm oil	18,860,000	++
Palm kernel cake	5,400,000	++
Rice	1,820,000	++
Soybean meal	410,000	++
Fishmeal	70,000	+
Brewer waste	62,000	+
Cassava	62,000	+
Maize	58,000	+
Copra/coconut cake	15,000	++
Groundnut meal	3,000	+
Cocoa meal	2,000	+
Wheat pollard	-	++
Wheat bran	-	++
Limestone	-	++
Molasses	-	++
Broken rice	-	++
Tapioca	-	+
Sago	-	+
Rice husk	-	++
Rubber seed meal	-	+
Oyster shell	-	++
Palm oil sludge	-	++

Notes: "++" commonly available; "+" less available.
Sources: Loh 2004; Indexmundi 2017.

Table 22. Availability of locally generated feed resources in Malaysia.



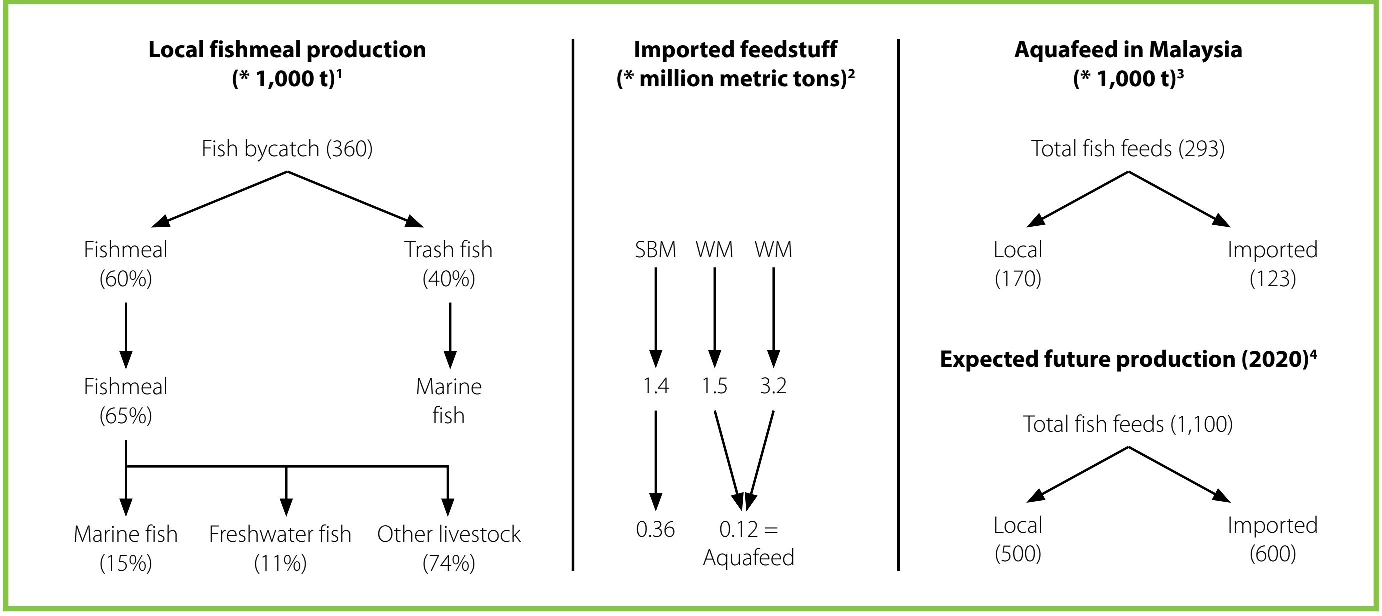
Source: editable map from: www.yourfreetemplates.com

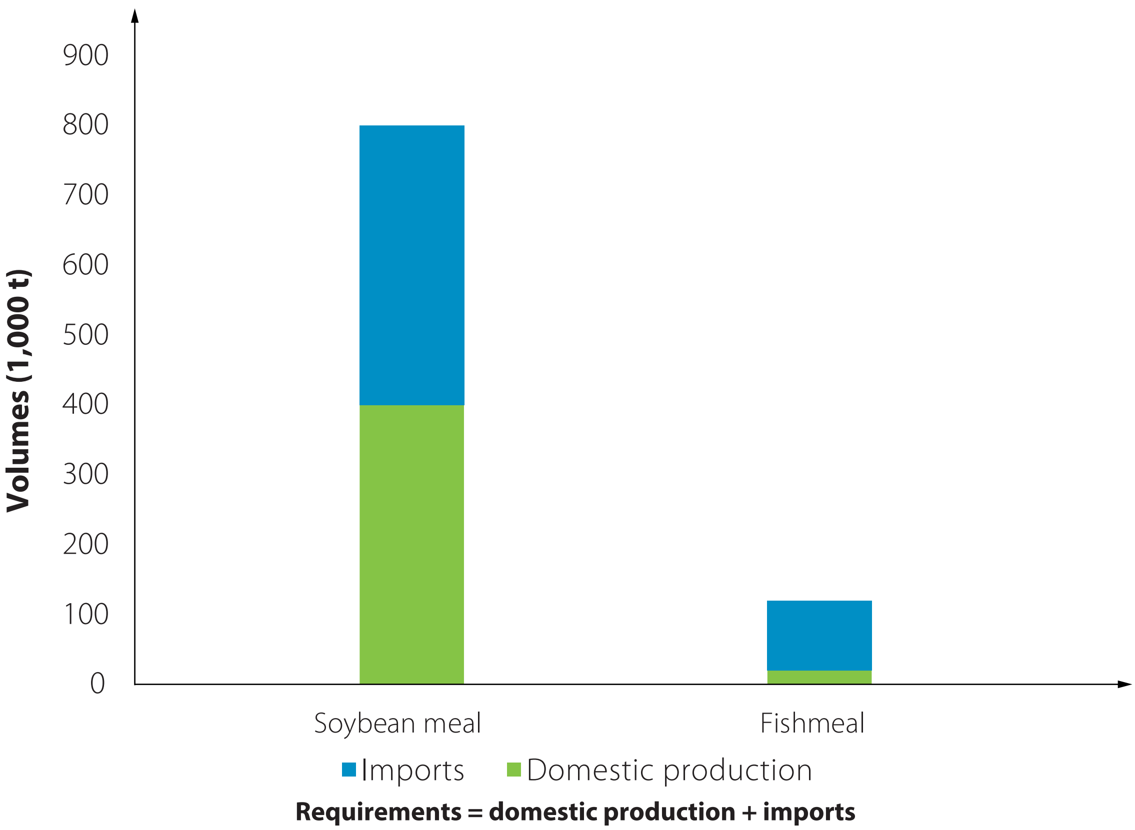
Figure 13. Crop distribution in Malaysia.

Box 1. Overview of the aquafeed industry in Malaysia (in metric tons).[7]

SBM – soybean meal; WM – wheat meal; CM – maize meal.

1. In 2012, 60% of fish bycatch as feed ingredient was used to produce 65,000 t of fishmeal, while 40% was fed directly to marine fish as discarded fish.
2. In 2014, imports (in million metric tons) of SBM, WM and CM were 1.4, 1.5 and 3.2, respectively, of which 460,000 t were used in aquafeed (360,000 t of SBM, and 120,000 t of WM and CM combined).
3. In 2015, 58% of total aquafeed was locally produced; the rest was imported.
4. By 2020, local aquafeed needs are expected to rise 460%, of which about half will be locally manufactured and the rest imported.





Source: Raghavan 2000.

Figure 14. Requirements of the main feed resources in Malaysia (t).

annually into Malaysia, substantial efforts should be geared toward improving both the quantity and quality of local production. Alternatively, if there is no capacity to increase local production, other prominently available feed resources should be used to replace soybean meal so as to reduce overreliance on imports.

Coconut meal

Coconut meal is an important co-product in the production of oil from dried coconut kernels (Feedipedia 2016). The protein content, amino acid profile and digestibility are less favorable in coconut meal compared with soybean meal. Nevertheless, it could be incorporated into aquafeed to reduce production costs. Approximately 16,000 t of coconut meal are currently produced in Malaysia (Indexmundi 2017). The nutritional content depends on the methods used (mechanical or solvent extraction) during the extraction process. Coconut meal produced in Malaysia has about 20% crude protein, 5% crude lipids, 10% ash, 37% crude fiber and 26% total carbohydrates (Table 24). If not done properly, drying coconut kernel prior to oil extraction can lead to mold growth and aflatoxin contamination. This usually results from sun drying, which is the cheapest and most available method in the country. To avoid contaminating quality meal, cheap, sustainable and effective drying methods should be employed during production. Aside from this, coconut meal contains high amounts of nonstarch polysaccharides, which reduces their use in monogastric nutrition (Alimon 2009).

Sunflower meal

Because it is not cultivated in Malaysia, sunflower meal must be imported. In 2012, there were 3255 t of sunflower seeds imported for sunflower oil production (FAOSTAT 2016). The production of sunflower oil extracted from sunflower seeds is mostly accompanied by a co-product known as sunflower meal, which is considered the fourth-most important oil meal after soybean meal, rapeseed meal and cotton seed meal (Feedipedia 2016). Sunflower meal has considerable nutritional value with, on average, 50% crude protein, 3% crude lipid, 8% ash, 12% crude fiber and 27% NFE (Table 24).

Palm kernel meal

Malaysia is second behind Indonesia in the production of palm oil seed and its co-products worldwide (Indexmundi 2017). Current palm oil seed production in the country is 4.5 million metric tons, out of which 2.75 million palm kernel meals are produced (Indexmundi 2017). Palm kernel meal (also known as palm kernel cake) is obtained after the extraction of oil, usually through the screw press or expeller methods. Palm kernel meal contains 16.8% crude protein, 5.20% fat, 6.55% ash, 17% crude fiber and 55% NFE (Table 24). The fiber level in palm kernel cake limit its use in monogastric animals, though supplementation with exogenous carbohydrase could ameliorate this. Aside from this, the inconsistent quality of palm kernel cake, attributable to its high shell content (more than 10%), is another impediment to its effective incorporation into aquafeed (Zahari and Wong 2009). More efficient and biotechnological methods are widely needed to improve the feeding value of palm kernel cake in fish. Previous efforts, in terms of fungal treatments and the use of specific microbes and enzymes, have been directed toward developing bio-processed palm kernel cake with improved energy availability (Zahari et al. 2009). Palm kernel cake has been previously considered as a feed ingredient in poultry (Zahari and Alimon 2004; Wong 2009), catfish (Zahari and Alimon 2004) and tilapia (Zahari and Alimon 2004).

Cocoa husk meal

Cocoa husk meal, which is produced from the outer kernel of cocoa pods, is a potential feed resource for aquaculture. In 2012, there were 2665 t of cocoa produced in Malaysia (FAOSTAT 2013). Donkoh et al. (1991) reported that cocoa husk, the by-product used to produce cocoa husk meal, accounts for 52%–76% of cocoa pods, which means approximately 1385–1918 t of cocoa husk were generated in Malaysia in 2012. The large quantity of husks generated from the production of dry pods presents serious challenges for waste management. As such they should be carefully recycled into other production sectors. Cocoa husk meal contains acceptable amounts of protein (12%) and fiber (25%) (Table 24); however, because of its high fiber content, further studies are needed to improve the digestibility of cocoa husk meal for fish.

Rubber seed meal

Another promising ingredient for aquaculture is rubber seed meal, which is a highly nutritious (Table 24) by-product of oil extraction from rubber seed. In 2014, there were 668,613 t of natural rubber produced in Malaysia, which means there is an abundancy of rubber seeds that could also be used as animal feed. To the author's knowledge, there is a paucity of quantitative data on the amount of rubber seeds produced in the country.

7.4.2 Protein sources: Animal origin

Fishmeal

Fishmeal production in Malaysia, which has a relatively low nutritional value compared to imported fishmeal, currently stands at 70,000 t per year (Indexmundi 2016). To meet the local demand, this is usually augmented with 15,000 t of imported fishmeal (Indexmundi 2016). Fishmeal is mainly manufactured from discarded small marine fish—such as scad, mackerel, sardine, tuna, anchovy and so on (Wan 2015)—which are usually considered unsuitable for human consumption, so it is mainly consumed for terrestrial animal production, particularly poultry. This often affects the consistency of the products because of the variability of fish used in producing fishmeal. The nutritional composition of fishmeal varies, but on average it contains 58% crude protein, 6% crude fat, 15% ash, 4% crude fiber and 17% NFE (Table 25).

Feather meal

Currently, 1.72 million metric tons of broiler meat are consumed in Malaysia, out of which almost 1.65 million metric tons are produced within the country (Indexmundi 2016). Production of other poultry species are ongoing within the country. As a result, enormous amounts of by-products, particularly feather waste, are constantly generated by the

Ingredient	Currently used in aquafeeds	Source
Palm oil	Yes	Local
Palm kernel cake	Yes	Local
Rice bran	Yes	Local
Soybean meal	Yes	Local and imported
Fishmeal	Yes	Local and imported
Brewers' dried grain	No	Local
Cassava flour and peel	Yes	Local
Maize meal	Yes	Local
Copra/coconut cake	No	Local
Groundnut cake	Yes	Local
Cocoa husk meal	No	Local
Wheat pollard	-	-
Wheat bran	Yes	Local
Broken rice	No	Local
Sago pith meal	No	Local
Rice husk	No	Local
Rubber seed meal	No	Local
Corn starch	-	-
Wheat flour	Yes	Local
Squid meal	No	Local
Feather meal	No	Local
Blood meal	No	Local
Distillers' dried grain	Yes	Local

Note: "-" information not available.

Table 23. Available ingredients (plant and animal origin) for aquafeed production in Malaysia.

Ingredient	DM	Crude protein	Crude lipid	Ash	Crude fiber	NFE	References
Palm kernel cake	93.23	16.80	5.20	6.55	16.57	54.88	a,b,c,d,e,f
Rice	87.80	8.53	2.15	1.43	NA	NA	g,h
Broken rice	NA	7.80	NA	NA	0.20	NA	i
Cassava root meal	85.00	2.65	2.60	1.60	3.35	89.80	b,
Sago pith meal	89.10	3.33	2.00	5.80	7.17	81.70	b,k
Alfalfa	92.00	19.00	3.00	11.00	26.00	41.00	b
Barley straw	88.00	4.00	1.90	7.00	42.00	45.10	b
Brewers' dried grain	92.00	23.00	7.70	3.70	16.50	49.10	b
Brewers' grains wet	24.00	26.00	6.50	5.00	15.00	47.50	b,l
Molasses cane	85.00	7.50	0.30	5.00	1.50	85.70	b
Maize stover mature	80.00	6.00	1.30	7.00	35.00	50.70	b
Maize cobs	90.00	3.00	0.50	2.00	36.00	58.50	b
Maize gluten meal	90.50	35.50	2.70	5.50	7.00	49.30	b
Distiller grain corn	91.33	29.33	8.20	3.87	11.33	47.27	b,e
Distiller dried soluble	93.00	30.00	9.50	8.00	4.00	48.50	b
Groundnut meal	91.00	52.00	1.30	5.00	11.00	30.70	b
Soybean meal	90.76	39.55	1.13	6.54	10.42	42.36	f,m,n,o,p
Sunflower meal	93.00	50.00	3.10	8.00	12.00	26.90	b
Leucaena leaf meal	51.22	21.94	5.35	4.66	17.39	50.66	m,q
Coconut meal	90.46	20.82	5.22	9.81	37.36	26.80	b,f
Rice bran	90.18	13.74	14.27	8.66	18.31	45.02	b,f,p,r,s
Cocoa husk meal	99.90	12.00	3.60	12.90	25.21	46.30	l,t
Wheat pollard	89.00	16.14	3.40	4.60	9.90	65.96	f
Rubber seed meal	96.00	17.41	68.53	3.08	NA	10.98	u
Mulberry leaf	90.46	27.31	4.27	11.81	13.99	42.63	v,w
Candle nut meal	95.26	22.94	66.46	1.00	5.02	4.58	x
Maize	88.99	8.31	1.22	0.85	13.40	76.22	f
Mushroom stalk	88.94	9.44	1.42	6.48	13.77	68.89	p
Wheat flour	NA	16.00	2.00	1.00	1.00	80.00	
Cassava flour	NA	12.00	7.00	5.00	6.50	69.50	

Sources: [a]Zahari and Wong (2009); [b]Alimon (2009); [c]Alimon (2004); [d]Sharmila et al. (2014); [e]Zulkifli et al. (2003); [f]Farahiyah et al. (2016); [g]Asyifah et al. (2012); [h]Fasahat et al. (2012); [i]BAKAR and Cp (1973); [k]Azilah et al. (2013); [l]Yeong and Faizah (1986); [m]Hamid et al. (2015); [n]Wan (2015); [o]Nor et al. (2011); [p]Muin et al. (2013); [q]Devendra (1986); [r]San Mu et al. (2011); [s]Rosniyana et al. (2007); [t]Ridzwan et al. (1993); [u]Eka et al. (2010); [v]Simol et al. (2012); [w]Al-kirshi et al. (2010); [x]Rohaida et al. (2014).

Table 24. Proximate percentage composition of major feed ingredients of plant origin in Malaysia.

poultry sector. These feathers can be processed into feather meal and incorporated into animal feeds. Feather meal varies in its composition because of the components used in production, but on average it contains 88% crude protein (Table 25). Despite this nutritional tendency, the presence of keratin is a major dilemma for including feather meal in animal diets. Animals, in general, lack endogenous keratinase to degrade keratin, which impedes the digestibility of feather meal. However, hydrolysing feather meal before feeding it to animals has been a major technique for getting rid of the negative impact of keratin.

Other by-products of the poultry industry that might be considered for aquafeed are fat and manure, as well as intestines and other uneaten parts of the carcass. Their nutritional composition is expressed in Table 25.

Prawn waste

Prawn processing waste is a potential protein source that is abundantly available in Malaysia. Prawn waste contains 47% crude protein, 6% lipids, 16.10% ash, 0.8% fiber and 30% NFE. The presence of chitin restricts its inclusion into animal feeds because of insufficient endogenous chitinase necessary to hydrolyse the chitin. However, chemical and microbial lactic fermentation methods have been used conventionally to recover chitin from the prawn waste to improve its digestibility in livestock animals (Nor et al. 2011).

7.4.3 Energy and fiber sources: Plant origin

Rice and its by-products

Rice is a by-product of rice milling. Annual rice production in Malaysia stands at 1.82 million metric tons—all of it consumed locally (Indexmundi 2017). Rice bran, depending on the processing methods, usually accounts for 10%–30% of unprocessed rice (Feedipedia 2016). This implies that rice bran production in Malaysia could potentially be 180,000–546,000 t annually. Rice bran is available year-round in Malaysia, but its inclusion in aquafeed is strongly restricted by its use in poultry and pig feeds.

Another by-product of rice is broken rice, which is made up of rice kernels that are 25% or shorter than the original length of the grain and are not considered fit for human consumption (Feedipedia 2016). Broken rice often represents 2%–3% of unprocessed rice, contingent upon the processing methods, so the potential annual production of broken rice in Malaysia is about 54,000 t. The nutritional composition of rice, rice bran and broken rice produced in Malaysia (Table 24) varies slightly: 7%–14% crude protein, 2%–14% lipids, 1%–8% ash and 1%–18% crude fiber. Some varieties of rice

Ingredient	DM	Crude protein	Crude lipid	Ash	Crude fiber	NFE	References
Fishmeal	89.99	58.01	5.84	15.32	4.30	16.53	a,b,c,d
Prawn waste	NA	47.30	6.10	16.10	0.80	29.70	e
Poultry fat	99.00	0.00	99.00	0.00	0.00	0.00	f
Feather meal	94.00	88.00	4.15	2.00	2.00	3.85	f
Animal manure	89.50	21.50	2.80	16.50	26.00	33.20	f
Blood meal	92.00	80.00	1.30	5.00	1.00	12.70	f
Fish silage	NA	56.53	8.46	32.27	0.69	2.05	b
Krill	NA	57.34	7.50	31.71	1.89	1.56	b
Poultry by-product	94.62	60.15	13.24	14.26	0.44	11.91	b,f,g,h
Cricket	89.78	49.87	12.47	6.33	5.55	25.79	i,j
Earthworm	90.82	60.34	NA	14.66	2.40	22.60	a
Black soldier fly	53.59	49.71	15.87	6.93	14.63	12.85	k,l
Squid meal	NA	25.00	9.00	7.00	NA	59.00	m

Sources: [a]Hamid et al. (2015); [b]Wan (2015); [c]Farahiyah et al. (2016); [d]Muin et al. (2013); [e]Nor et al. (2011); [f]Alimon (2009); [g]Shapawi et al. (2007); [h]Saadiah et al. (2011); [i](Norhidayah, 2016); [j]Razak et al. (2012); [k]Al-Qazzaz et al. (2016); [l]Muin et al. (2017).

Table 25. Proximate percentage composition of major feed ingredients of animal origin in Malaysia.

(brown rice) are not fit for human consumption because of an absence of certain nutrients, so they have been purposely cultivated for animal consumption in Malaysia (Asyifah et al. 2012).

Maize and its by-products

The annual production of maize in Malaysia currently stands at 58,000 t (Indexmundi 2017). Maize is the major component of the compound feed given to nonruminants, particularly poultry and pigs (Loh 2004). As a result, large quantities of maize are imported yearly to augment both human and animal requirements. Between 3.8 and 4 million metric tons of maize are imported annually in Malaysia, especially from China, the US and Argentina (Indexmundi 2017). Malaysia must either look inward and improve its yearly maize production or explore alternative locally generated feed resources to prevent excessive dependence on maize. The major challenges confronting increased production of local maize are limited areas of suitable land for large-scale cultivation, coupled with erratic weather conditions for optimum drying during harvesting (Zahari and Wong 2009). Nonetheless, several by-products, such as maize flour, maize cobs and maize stover, could be used in aquafeed. The nutritional composition of these by-products is presented in Table 24.

Distiller grains

Distiller grains, a co-product of grain fermentation, accounts for 30% of dry grain for ethanol production (Alimon 2009). The co-product is classified into distillers' dried grain (DDG), which is the dried residue from distillers' grain, and distillers' dried grain with soluble (DDGS) containing DDG with syrup (Alimon 2009). The nutritional composition of these different by-products varies: 29%–30% crude protein, 8%–10% crude lipid, 3%–8% ash, 4%–11% crude fiber and 46%–50% total carbohydrates (Table 24).

Brewery waste

Beer production, both alcoholic and nonalcoholic, is normally accompanied by enormous amounts of waste products. One in particular is spent grain (brewers' dried grain), which is the residue left after the processing and fermentation of cereal grains. This co-product varies depending on the type of cereal used, processing parameters and preservation methods. The nutritional composition also differs depending on the moisture levels, as well as the drying methods employed: 23%–26% crude protein, 6%–8% lipids, 3%–5% ash, 15%–17% crude fiber and 43%–50% NFE (Table 24). The by-products of beer production represent 20% of the total volume of beer produced (Mussatto et al. 2006). In 2013, about 300,000 t of beer were produced in Malaysia (FAOSTAT), which means that about 60,000 t of co-products were generated. Yet despite large amounts of by-products from beer production, their high moisture content significantly constrains their incorporation into aquafeed, which means products need to be dried and processed before they can be used as feed ingredients. Additionally, the potential of feeding terrestrial animals with these products also limits their inclusion in aquaculture production.

Sago pith meal

Sago, which is a type of palm grown on peat soils and in wetlands, is abundantly available in Malaysia. A high concentration of starch is embedded within the trunk of palm, which has been harvested for both human consumption and industrial purposes (Alimon 2009). The pith can be harvested, dried and milled to produce sago pith meal, which is a high energy ingredient that can be used in animal feed (Alimon 2009). In addition, sago waste can be generated after extracting the starch from the pith and can contain up to 20% starch depending on the extraction method (Alimon 2009). Sago pith is not rich in protein, but it does contain a relatively high proportion of total carbohydrates (Table 24).

Cassava by-products

A number of cassava by-products can be used as animal feeds, including cassava peel, cassava root meal and cassava leaf meal (though cassava root is unavailable for animal feeding because it is largely consumed by humans). Nevertheless, the peel as well as the root are abundantly available for animal feed. It is well known that cassava peel makes up about 15% of the entire root. So since about 62,000 t of cassava were manufactured in Malaysia in 2013, roughly 9300 t of peels were generated in 2013. As stated earlier, different products are generated from cassava plants, and this invariably influences the nutritional composition of the resulting by-products. The major obstacle to using cassava by-products in animal feed is their low protein level. Other obstacles include their high moisture content and the presence of hydrogen cyanide. Therefore, cassava peels need to be supplemented with another high protein feedstuff and/or synthetic amino acids to improve fish performance.

7.4.4 Priority aquafeed ingredients for further research in Malaysia

Priority ingredients for further research activities in Malaysia are listed in Table 26. These are mainly produced locally in Malaysia. Future research in Malaysia can be tailored toward improving the nutritional content of locally available plant protein sources, which can be used to augment the local fishmeal used in fish feeds.

7.4.5 Conclusions for Malaysia

Although fishmeal is locally produced in Malaysia, the quantity is insufficient to meet domestic demand. Instead, imported fishmeal is used to augment locally produced fishmeal in animal feeds. Squid meal, feather meal and blood meal are other protein sources of animal origin that can be considered for aquafeed production, but information on the amounts available within the country is lacking. Palm kernel cake is abundantly available, but its use in aquafeed is limited by its high lipid content. Other important plant ingredients of importance that could be used as protein sources for aquafeeds in Malaysia are copra meal, groundnut cake, soybean meal and brewers' dried grain. Future efforts should be focused on understanding the quantities of these plant sources available in Malaysia. Rubber seeds and broken rice are available in small amounts and could be considered as aquafeeds ingredients. Additionally, the prospects of novel feed ingredients, such as insect meal, algae meal and microbial biomass, could also be explored in the future.

Ingredient	Research action(s) needed
Protein sources	
Fishmeal	• Further information needed on the volume of local fishmeal produced within the country. • Improve processing methods to increase the protein content of locally produced fishmeal compared with conventional fishmeal (imported from Peru/Denmark).
Palm kernel cake	• Improve processing methods to decrease both lipid and fiber contents in local palm kernel cake. • Improve processing methods to increase the protein content in local palm kernel cake.
Soybean meal	• Further information needed on the volume available within the country. • Find alternative protein sources to augment the use of locally produced soybean meal.
Copra meal	• Further information needed on the available volume of copra meal in Malaysia.
Groundnut cake	• Further information needed on the available volume within the country. • Improve processing methods to decrease the amount of mycotoxin present in locally produced groundnut cake.
Squid meal	• Further information needed on the volume available within the country.
Feather meal	• Improve collection and processing methods to increase availability of feather meal for aquafeeds.
Blood meal	• Improve collection and processing methods to increase availability of blood meal for aquafeeds.
Brewers' dried grain	• Further information needed on the volume available within the country. • Improve processing methods to increase level of protein in brewers' dried grain.
Energy sources	
Maize meal	• Replace with quality alternatives, with less competition from humans and livestock.
Maize bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Cassava flour	• Increase the inclusion level through appropriate research without compromising fish growth. • Investigate the use of cassava by-products, such as cassava peels and leaves.
Distillers' dried grain	• Further information needed on the quantities available for aquafeed production.
Wheat flour	• Replace with quality alternatives, with less competition from humans and livestock.
Wheat bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Sago pith meal	• Further information needed on the quantities available within the country.

Table 26. Priority ingredients for further consideration in aquafeeds and proposed research to improve their nutritional quality.

8. Country review: Egypt

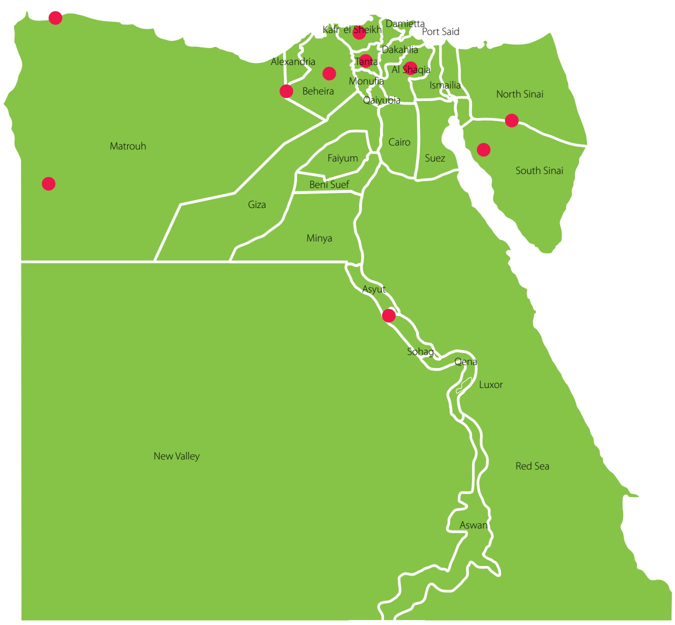
8.1 Introduction

Egypt's total area is 1,001,450 km^2, with 995,450 km^2 of land and 6000 km^2 of water. The country is generally divided into five regions: the Nile River Valley, the Nile Delta, the Western Desert, the Eastern Desert and the Sinai Peninsula (Goldschmidt Jr 2008). The Nile River, which is so important for Egypt's economy, is used to transport goods and services within the country. There is limited arable land in Egypt because it lies in a dry desert region, except a rain-fed strip on its northern coast. It has 3 million ha of total cultivated land, representing roughly 3% of its total land mass (Maqbool and Kerry 1997). Egyptian agriculture, which is almost exclusively dependent on irrigation from the Nile River, accounts for about 20% of GDP, 34% of total exports, 32% of the labor force and a significant proportion of the country's food supply (Abdel Hadi 2004). Field crops make up 90% of the total cropped area, while the rest is covered by vegetable and fruit crops. Traditionally, cotton has been the most important export crop, though maize (315,000 ha) and rice (210 ha) contribute to the economy as well. Table 27 lists the major agricultural crops produced in Egypt in 2016, while Figure 16 shows their distribution. Apart from the limited cultivable land, inadequate access to modern technology and credit, poor infrastructural development and political instability are reported as possible causes of the stunted growth of agriculture in Egypt.

8.2 Aquaculture in Egypt

The practice of aquaculture in Egypt can be traced back many centuries ago. However, the modernization of the sector did not start until the 1930s, when common carp was introduced into two research farms solely for the purpose of research (FAO 2003). The first modern semi-intensive commercial farm began in 1961, with 120 ha of earthen ponds for growing Nile tilapia, common carp and grey mullet (FAO 2003). The main aquaculture area in Egypt is the Northern Nile Delta region, with farmed fish generally found in the area surrounding the four delta lakes—Maruit, Edko, Boruls and Manzala—and fish hatcheries also scattered in the vicinity (FAO 2003).

The distribution of aquaculture spots is shown in Figure 15. From the 1960s onward, the sector has witnessed significant expansion, particularly in the past two decades. During this period, aquaculture output grew from 63,855 t in 1992 to 1,017,738 t in 2012, constituting about 74% of total production (El-Sayed et al. 2015), and the farmed area increased by 300% between 1999 and 2012



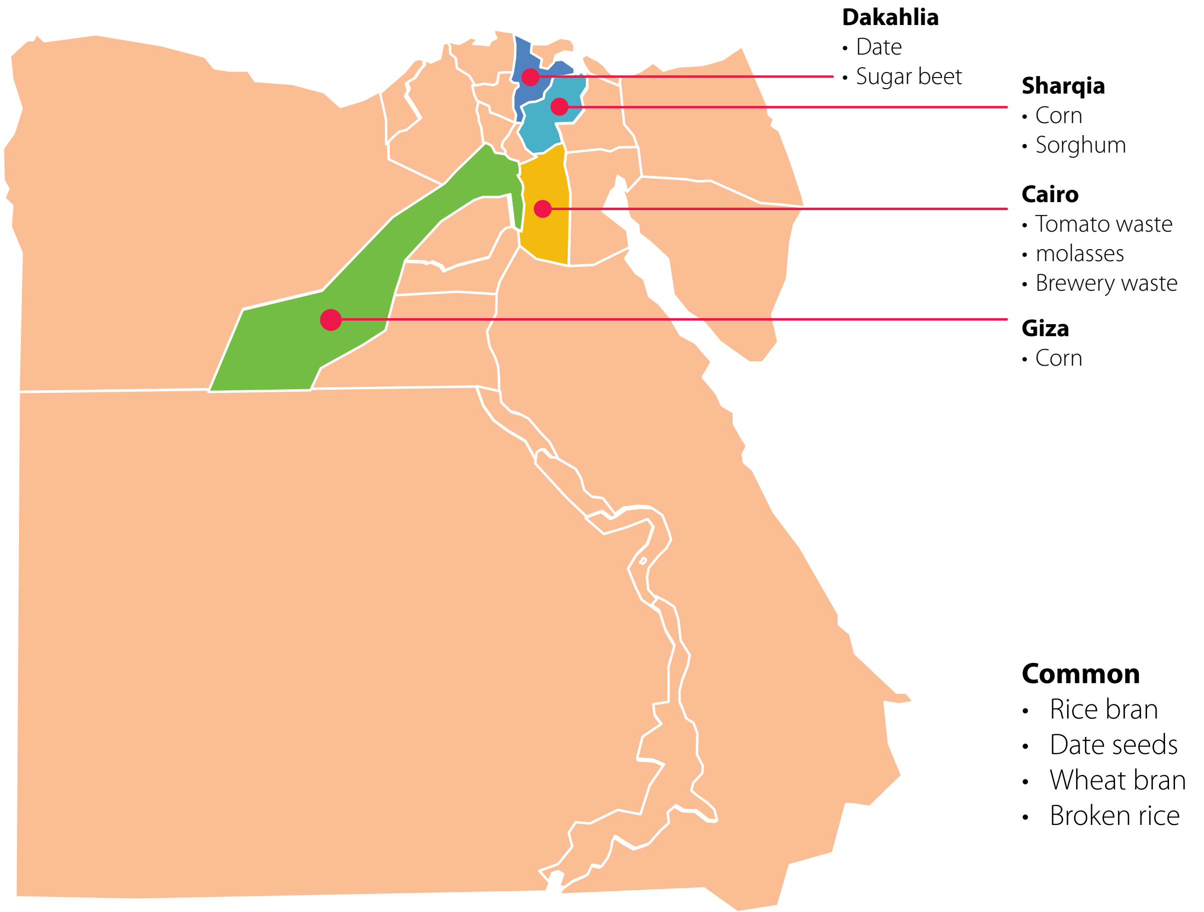
Source: modified from FAO 2003.

Figure 15. Governorates and aquaculture spots in Egypt.

Crop	Yield (t)	Availability	By-products
Sugar cane	15,760,000	++	Cane pulp
Sugar beet	13,323,000	++	Beet pulp
Wheat	9,279,000	+++	Bran, meal
Rice	6,300,000	+++	Bran, broken rice
Maize	6,000,000	....	Meal, bran
Date seed	1,465,000	+++	Meal
Tomato	829,000	++	Tomato waste
Sorghum	750,000	.....	Meal
Groundnut oil seed	205,000	++	Cake, oil
Cotton seed	175,000	+	Cake, oil
Barley	120,000	++	Meal, brewers' dried grain
Sesame seed	45,000		Meal, oil
Soybean seed	35,000	+	Meal, oil
Sunflower seed	17,000	+	Meal, oil
Linseed (flaxseed)	4,000	....	Meal and oil

Source: FAOSTAT 2016.

Table 27. The total production of agriculture crops in Egypt (2016).



Source: editable map from: yourfreetemplates.com

Figure 16. Distribution of crops in Egypt.

(El-Sayed et al. 2015). Currently, Egypt is by far the largest aquaculture producer in Africa and the second-largest producer of tilapia in the world. Approximately 940,309 t of tilapia were produced in 2016 (GAFRD 2016), and the total market value of the sector was estimated at USD 2.2 billion in 2015 (USDA 2016). An overview of aquaculture systems in Egypt is summarized in Table 28, while total aquaculture production by species and production systems in 2004 is presented in Table 29.

System	Culture species	Stocking density (fish/ha)	Stocking ratio	Pond size (ha)	Fertilization and feeding	Rearing period (months)	Harvest size (g)	Total yield (t/ha)
Extensive								
Polyculture	Tilapia, mullet, seabream, seabass, carp, catfish	Natural populations	Varies	5 to over 40	Depends mainly on available natural food, without fertilization	9–14	Varies	0.25–0.75
Semi-intensive								
Polyculture in brackish water pond	Tilapia, mullet, carp	15,000–30,000	Varies	0.5–13	2–5 t of poultry manure with 29 kg of super phosphate and 18 kg urea/ha; 25% CP feed	7–12	100–500	5–10
Monoculture	Tilapia (mainly all male)	15,000–30,000		0.5–2	2–5 t of poultry manure with 29 kg of superphosphate and 18 kg urea/ha; 25% CP feed	7–9	200–400	5–10
Intensive								
Monoculture	Tilapia (mainly all male)	50,000–100,000		0.25–0.5	35%–40% CP feeds at the beginning, reduced to 25% CP during fattening	7–10	200–400	15–25
Polyculture	Tilapia, grey mullet	50,000	3:1	0.5–1	36% CP feeds at the beginning, reduced to 25% CP during fattening	9–12	200–300	15–20
Cage culture	Tilapia (mainly all male)	60–100 fish/m^3			35%–40% CP feeds at the beginning, reduced to 25%–30% CP during fattening	8–14	300–400	25–35 kg/m^3

Source: El-Sayed 2007.

Table 28. An overview of typology of aquaculture systems in Egypt.

Species	Ponds*	Rice fields	Cages	Other rearing facilities**	Total
Nile tilapia	859,109	4,061	74,996	2,143	940,309
Common, silver and largehead carp	99,974	6,768	94,167	-	200,909
Mullet nei	147,479	-	6,250	47	153,776
Gilthead seabream	26,663	-	-	-	26,663
European seabass	24,270	-	219	9	24,498
Meagre	16,162	-	-	-	16,162
Catfish	4,855	2,706	-	66	7,627
Caranx spp.	612	-	-	-	612
Shrimp nei	101	-	-	-	101
Eels nei	-	-	-	3	3
Total	**1,179,225**	**13,535**	**175,632**	**2,268**	**1,370,660**

Notes: "" both private and government owned; "**" other rearing facilities include concrete tanks, floatable tanks, recirculating aquaculture systems and flow through systems.*
Source: GAFRD 2016.

Table 29. Aquaculture production (t) by species in 2016.

8.2.1 *Hosha* (extensive) culture system

Extensive systems are characterized by a low level of intervention, restricted use of inputs, low capital investment and poor management (El-Sayed 2007). The farms were developed from natural water enclosures, such as lagoons, rivers and lakes, through reinforcement of their embankments. The fish trapped in these enclosures (known as *hosha* in Arabic) rely strictly on natural food, and this usually results in a lower yield (about 250–750 kg/ha) (El-Sayed 2007). This form of aquaculture is predominantly found around the northern lakes, but the destructive tendency of this system on lake fisheries and the environment has led to its abolishment (El-Sayed 2007), though some such farms still exist (El-Sayed 2007).

8.2.2 Earthen pond culture

Semi-intensive fish cultivation in earthen ponds is the most widespread farming system in Egypt. In 2004, 86% of farmed fish produced in Egypt came from this system (El-Sayed 2007), which is characterized by moderate interventions in term of fertilization and supplemental feeding. Polyculture of Nile tilapia, mullet and carp is predominantly practiced under this system, but there are a few cases where only Nile tilapia is farmed. The net yield from the system varies from 5 to 10 t/ha and is higher than under extensive systems. Supplemental feeding contains less crude protein (25%) compared to cage culture (40%). The fish reach marketable weight of 200–400 g in 7–10 months.

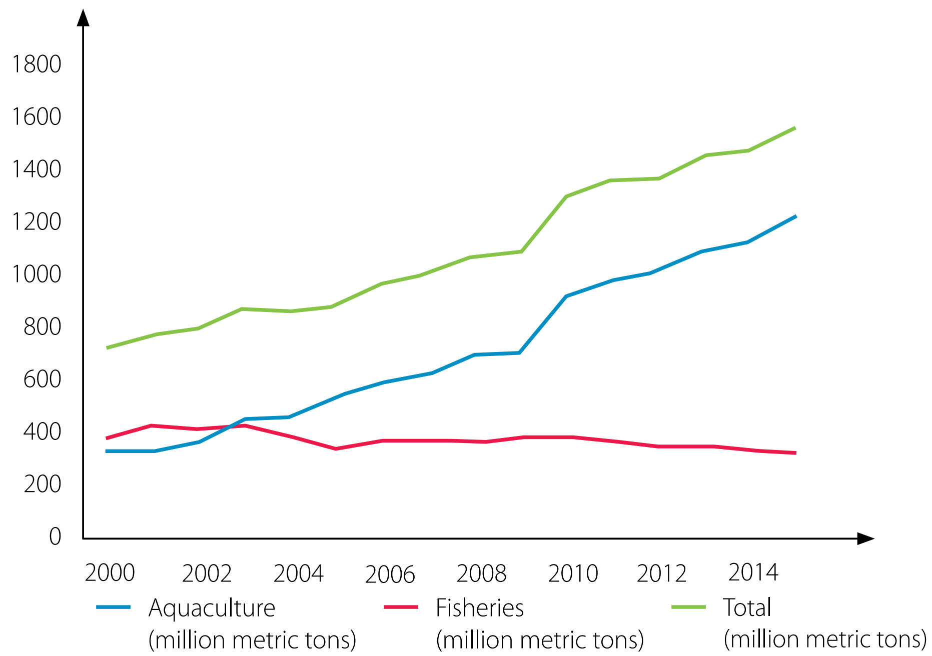
8.2.3 Intensive cage and pond culture systems

Intensive culture systems are usually conducted in ponds and cages. Intensive cage cultures are situated in the Domiat and Rashid (Rosetta) branches of the Nile River and in the northern Delta lakes region (Lake Manzala and Lake Borullos) (El-Sayed 2007). Production from cages surged rapidly from 12,900 t in 1999 to 175,000 t in 2016, accounting for about 13% of total aquaculture production (GAFRD 2016). Cage sizes range from 32 to 600 m^3.

Intensive pond cultures are usually situated in newly reclaimed agricultural lands in the desert. In both intensive pond and cage systems, Nile tilapia is the major culture species, and these are fed with commercial feeds containing 30%–40% crude protein. The productivity of the fish, in terms of biomass yield, is considerably higher than in both extensive and semi-intensive systems.

8.2.4 Rice-fish culture system

Rice is a widely cultivated and consumed staple food in Egypt, and integrated rice-fish farming has improved tremendously in recent years. Carp is the dominant species cultivated with rice. Carp production in rice fields increased from 10,000 t in 1999 to 17,203 t in 2004 at annual average yields of 300–500 kg/ha (El-Sayed 2007). In Kafr El-Sheik Governorate, some farmers practice another form of integrated fish farming by cultivating wheat and/or alfalfa in fishponds and flooding them in spring (El-Sayed 2007). Most of the time, the



Source: USDA 2016.

Figure 17. Trends of fish production in Egypt (2000–2015).

crops are left unharvested and allowed to decay in the ponds, which provides nutrients for fish production (El-Sayed 2007). Figure 17 shows the growth of aquaculture in Egypt.

8.3 Aquafeed resources in Egypt

The rise in aquaculture in Egypt is mainly attributed to the advent of new technologies, such as floating feeds, recirculation systems and improved farm management practices. At the same time, growth has been accompanied by increased levels of inputs, such as feeds and fertilizers. The expansion of Egyptian aquaculture is expected to be sustained in the future because of expected population growth, increased domestic demand and a shift in the diet of low-income consumers toward fish (USDA 2016). The use of feed and feed ingredients will have to rise to match the expected expansion.

Previously, an estimated 54%–99% of ingredients used in aquafeed production in Egypt have been imported (El-Sayed et al. 2015), and in recent years the prices of feed ingredients and commercial feeds have increased substantially. El-Sayed et al. (2015) reported that between 2002 and 2011 prices rose 280% for soybean seeds, 206% for soybean oil, 170% for sunflower oil, 147% for maize and 123% for wheat. This increase in the price of feed ingredients coupled with the recent dwindling economic situation in the country means there is an urgent need to include alternative feed resources, especially low-value agricultural by-products, in aquafeed production. This section highlights possible feed ingredients that could be incorporated into aquafeed in Egypt.

8.3.1 Current feed ingredients in Egypt

Based on discussion with different respondents in Egypt, the most commonly used feed resources are listed in Table 30 and their nutritional composition is represented in Table 31.

8.3.1.1 Protein sources: Plant origin

Soybean meal

In Egypt, soybean meal is the second-most used protein source in aquafeed, after fishmeal, with about 25,000 t of soybean seeds produced in 2016 (Table 27), but it is mainly used for human consumption. A large proportion of soybean meal incorporated into aquaculture feed production is mainly imported from Brazil, the US and Argentina. In 2015, Brazil was the largest supplier of soybeans to Egypt at 550,000 t, followed by Argentina at 540,000 t and the US at 480,000 t (USDA 2016). Other sources of imported soybeans are Canada, Uruguay, Paraguay and Ukraine. The recent devaluation of the Egyptian Pound against the US Dollar is the biggest constraint confronting the import and eventual use of soybeans in aquafeed, because it has sharply increased the price of aquafeed. The price of imported soybeans jumped from USD 345/t in 2016 to USD 407/t in 2017 (author's field survey 2017). There is a clear need to increase local production within the country. Additionally, locally produced soybeans are reported not to be appropriate for soybean meal production. The pods are green after harvest, and this mostly results in greenish coloration of the extracted oil, which restricts sales in the market (Osama Solimon and Seif Omar, Cargill Egypt, personal communication, 2017). Farmers need to be sensitized on the optimum conditions and appropriate harvesting time to produce quality local soybeans for both soybean meal and soybean oil production.

Sunflower meal and oil

The field survey revealed that nearly all sunflower meal used for aquafeed in Egypt is imported, but there is evidence of sunflower seed production within the country, with about 17,000 t produced in 2017. In 2007, about 115,000 t of sunflower oil were imported to the country, which were largely used for human consumption.

Cotton seed meal and oil

The decreasing quantity of cotton seed meal produced in Egypt (as shown in Figure 18) has led to a lower quantity of cotton seed meal currently used for aquafeed compared to before. Until now, cotton seed meal had been the most important plant protein source used in the Egyptian animal feed industry because of its availability and lower price (El-Sayed 2007). Cotton seed meal is mainly produced in corticated form (with hulls), but there is also small proportion of the decorticated form. Decorticated cotton seed meal is richer in crude protein (47%) than the corticated kind (27%).

Flaxseed (linseed) meal

Flaxseeds come from flax plants, which are grown for their oil or fiber content. Flaxseed meal, the by-product remaining after extracting the oil

Ingredient	Currently used in aquafeeds	Source
Wheat	No	Local
White maize	Yes	Local
Yellow maize	Yes	Local
Sorghum	No	Local
Barley	No	Local
Kidney bean	No	Local
Soybean meal	Yes	Local and imported
Cotton seed meal	Yes	Local
Sesame seed	No	Local
Lentil seed cake	No	Local
Broken rice	No	Local
Rice bran	Yes	Local
Distiller dried grain soluble (DDGS)	Yes	Imported
Flaxseed (linseed)	Yes	Local
Wheat bran	Yes	Local
Maize gluten	Yes	Imported
Beet pulp	No	Local
Sugar cane bagasse	No	Local
Sugar cane pulp	No	local
Sunflower seed meal	No	Local
Groundnut cake	Yes	Local
Blood meal	No	Local
Fishmeal (local)	Yes	Local
Fishmeal (imported)	Yes	Imported
Meat and bone meal	Yes	Imported
Poultry by-product meal	Yes	Imported
Shrimp meal	Yes	Local
Feather meal	Yes	Imported

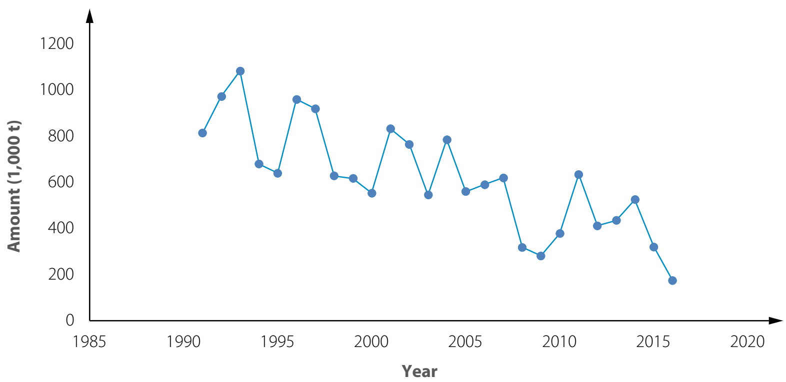
Source: author's field survey 2017.

Table 30. Available ingredients (both plant and animal origin) for aquafeed production in Egypt.

Ingredient	DM	Crude protein	Crude lipid	Crude fiber	NFE	Ash
Plant products						
Wheat	88.9	8.3	1.8	3.8	84.3	1.8
White maize	89.7	9.1	4.8	7.2	77.5	1.4
Yellow maize	92.1	8.3	2.9	2.1	84.6	2.1
Sorghum	89.0	9.2	4.2	2.9	82.5	1.2
Barley	86.8	10.1	1.6	8.2	77.1	3.0
Kidney bean	90.2	28.0	1.0	5.7	59.8	5.5
Soybean meal	86.5	45.5	16.9	7.5	24.6	5.5
Cotton seed meal (with hulls)	92.5	27.1	8.5	21.4	36.1	6.9
Cotton seed meal (without hulls)	92.9	44.4	10.1	5.2	32.8	7.5
Sesame seed (with hulls)	91.0	30.2	14.4	18	20	17.4
Lentil seed cake	81.5	13.3	10.7	7.1	61.4	7.5
Rice, broken, polished	90.8	11.0	7.8	1.1	75.9	4.2
Rice bran	89.5	13.0	12.1	10.3	57.1	7.5
Wheat bran, coarse	88.0	11.1	3.6	17.8	63.2	4.3
Wheat bran, fine	88.0	17.1	3.0	9.4	66	4.5
Maize gluten	94.1	43.9	3.2	4.4	44.8	3.7
Sugar cane bagasse	96.8	1.3	0.4	51.1	44.5	2.7
Animal by-products						
Blood meal	90.7	81.2	1.0	-	-	5.3
Broken eggs	95.8	34.7	15.0	-	-	25.5
Fishmeal (local)	89.7	65.3	10.5	-	-	16.7
Fishmeal (imported)	91.0	70.0	6.1	-	-	11.6
Animal gelatine	88.6	85.7	3.1	-	-	-
Meat and bone meal	95.4	61.8	6.0	-	-	26
Poultry by-product meal	87.0	53.9	23.0	-	-	18.2
Shrimp meal	87.3	51.7	5.6	-	-	26.9

Source: adapted from El-Sayed 2007.

Table 31. Percentage nutritional composition of aquafeed ingredients used in Egypt.



Source: FAOSTAT 2016.

Figure 18. Cottonseed production in Egypt.

from the flaxseeds, is incorporated into aquafeed, especially by farmers who are into farm-made feed production, and it contains 14% crude protein and 7%–8% lipids (author's field survey 2017). Only a small quantity of flaxseeds is produced in Egypt (about 4000 t in 2016) (Table 27).

8.3.1.2 Protein sources: Animal origin

Fishmeal

Both local and imported fishmeal are available for aquafeed in Egypt. In general, imported fishmeal is highly nutritious, with 60%–72% crude protein compared to 30%–40% in local fishmeal (author's field survey 2017). Fishmeal is imported from Denmark, Peru, Chile, Morocco and Yemen. The production and quality of local fishmeal is very inconsistent. Only a negligible amount (200–400 t) was produced by the Edfina Preserved Food Company in 2007 (El-Sayed 2007). As a result, large-scale feed manufacturers are dependent on imported fishmeal, whereas small-scale semi-automated feed millers mostly use local fishmeal. Over the past decade, the price of imported fishmeal has doubled from USD 700 in 2004 to USD 1500 in 2017 (author's field survey 2017), mainly from the sharp decline in the value of Egyptian Pounds against the US Dollar. In 2007, an estimated 10,000–20,000 t of fishmeal were used by the Egyptian aquafeed industry, but that has likely skyrocketed because of the upsurge in aquaculture in recent years.

Poultry meal

Poultry meal, which comes from rendering the inedible parts of processed poultry, is produced locally by large-scale processing companies. It has an appreciable crude protein content of 50%–60% and is used as a partial replacement for fishmeal in aquafeed (El-Sayed 2007). The demand for poultry meal, in part, is constrained by increasing consumer concerns of mad cow disease and other potential health implications (El-Sayed 2007).

Shrimp meal

Shrimp meal is another animal protein source that is highly used in aquafeed. It is produced locally, from brackish water and coastal lagoons (Port Fouad lagoon) near Port Saied (El-Sayed 2007), by sun drying, milling and packaging for use as protein in aquafeed. It contains about 45% crude protein (author's feed survey 2017).

8.3.1.3 Energy and fiber sources: Plant origin

Maize and maize gluten

Maize production is ongoing in different parts of the country, with about 6 million metric tons of both white and yellow maize produced in 2016 (Table 27). Yellow maize is used mainly by the animal feed industry whereas white maize is meant for human consumption. However, local production of yellow maize falls short of the amount required by the animal feed industry, so large amounts have had to be imported, chiefly from Argentina and Brazil. Egypt imported 2.4 million metric tons of yellow maize in 2004, out of which around 510,000 t were used in the cattle and poultry feed industry (El-Sayed 2007). Another maize by-product that is mostly imported and used in aquafeed is maize gluten, which is the by-product of wet-milling of maize grains for starch or ethanol production.

Rice bran, broken rice and rice polish

Rice is widely produced in Egypt, part of which becomes rice bran through milling. In 2016, the country produced 6 million metric tons of rice (Table 27). About 130,000 t of rice bran was produced in 2004 (El-Sayed 2007). Despite the significant amount of rice bran production in Egypt, only a small proportion is used in aquafeed. The rest is mainly available for terrestrial animal production, particularly poultry and large animals, so competition from other livestock is the main dilemma affecting the availability of rice bran for aquafeed production. In addition, the seasonal nature of the crop leads to fluctuations in availability and price (El-Sayed 2007). Rice production is seasonal, but the volume produced is sufficient to have a year-round supply of rice bran for the animal feed industry. Broken rice, which is a lower grade rice unfit for human consumption, is another by-product of rice currently used in animal feeding, and its potential in aquafeed should also be explored. Rice polish is readily available in Egypt and contains 14%–15% crude protein and 14%–15% crude fiber (Skretting Egypt 2018).

Wheat and wheat bran

Even though the government of Egypt prohibits the use of wheat grain in animal feed, it remains the most commonly used energy source in animal feed. In 2016, the country produced 9.2 million metric tons of wheat (Table 27). In addition, 12 million metric tons were imported from the US, Argentina and other countries (Indexmundi 2017). An estimated 2 million metric tons of wheat bran were produced in 2004 (El-Sayed 2007). At that time, the total amount of wheat (from local and imported sources) was nearly one-third of the current amount in Egypt, which means roughly 4–6 million metric tons of wheat bran is currently generated within the country. In 2007, an estimated 50,000 t of wheat bran were used in aquafeed for both commercial feed mills and in farm-made feeds (El-Sayed 2007). Therefore, the recent growth of aquaculture in the country implies that the amount of wheat bran currently used in aquafeed is far above the levels reported in the previous years (2010–2014). The terrestrial animal feed sector is the main competitor to using wheat bran in aquafeed. In 2003, a total of 704,263 t of wheat bran were used for cattle feed and 3991 t for poultry feed.

8.3.2 Potential feed ingredients in Egypt

8.3.2.1 Protein source

Groundnut (peanut cake)

Large quantities of groundnut are also produced in Egypt, with about 200,000 t generated in 2016 (Table 27). Groundnut produced in Egypt seems not to be used for oil production (Alaa Badr, Skretting Egypt, personal communication, 2017). Groundnut cake is mainly imported from Sudan. Its nutritional composition is varied and it is susceptible to aflatoxin contamination because of processing and storage methods (Alaa Badr, Skretting Egypt, personal communication, 2017). Apart from groundnut meal, groundnut oil is another valuable raw material that could be explored and considered for aquafeed.

Sesame meal

Sesame meal is a good plant protein source for aquafeed. However, in Egypt sesame is considered a food crop rather than an oil seed crop because its seeds are consumed directly (El-Lattief 2015). This explains why sesame meal is not available as an animal feed resource. Egyptian production of sesame seeds currently stands at 47,000 t, a leap from about 32,000 t produced in 2012 (FAOSTAT 2016). Sesame is grown in many governorates but ranks first among the oil seed crops grown in Ismail Governorate (El-Lattief 2015). Sesame meal is currently sold in small scales, making it unsustainable for long production runs (Alaa Badr, Skretting Egypt, personal communication, 2017). Large-scale production of sesame meal and sesame oil to use in aquafeed is another important area for future exploration in the country.


Photo credit: Agboola J.O/WorldFish

Feed manufacturers interview in Egypt.

Feather meal

Feather meal, a by-product of poultry processing, is an excellent source of protein and energy that could be used in aquafeed. Egyptian poultry production in 2005 was 874,000 t (El Nagar and Ibrahim 2007) and it assumed to be even higher today because of the sector's sharp growth over the past decade. Feathers are known to make up 7%–10% of the total live weight of chicken, so annual production of feathers stands at an estimated 62,000 t or more. Feather meal produced domestically is of lesser quality because it is hydrolyzed without separating offal, legs or heads, which lowers the crude protein content to 60% and contributes to low digestibility coefficients (Alaa Badr, Skretting Egypt, personal communication, 2017). Also, local feather meal contains 17%–20% fat, which can be partially separated to increase the protein content and can be used separately as a lipid source (Alaa Badr, Skretting Egypt, personal communication, 2017).

Blood meal

As discussed under the feather meal section, large numbers of animals are constantly produced in Egypt, whether poultry, cattle or, especially, rams during the Muslim *eid-al-adha* festival. Slaughtering these animals produces a lot of blood, which can be processed and incorporated into aquafeed. Blood meal is currently an untapped ingredient to be used in the feed industry.

8.3.2.2 Other nutrient sources

Barley

Barley production is concentrated in the New Valley and Sharkia governorates, but there are traces of production in other regions of the country, such as Fayoum, Behera, Kafir El Sheikh and Ismaila. Egyptian barley production was about 120,000 t in 2016 (Table 27) and currently it is not used for aquafeed production in the country. It is exclusively used for human consumption. Although residue from brewing beer, such as barley distillery by-products, can be used in the animal feed industry, there is no official data on the quantity of these by-products available within the country.

Sorghum

Sorghum is another agricultural crop produced in enormous amounts in Egypt, with 750,000 t manufactured in 2016 (Table 27). Most sorghum production takes place in the governorates very close to the Nile—Asyut and Suhag—with a few thousand metric tons produced in Fayum, Giza and Menia governorates. Sorghum is mostly reserved for human food, but its by-products, such as bran, brewer's waste, gluten meal and sorghum germ meal, can be considered animal feedstuffs, particularly for aquafeed. Ethanol production from sorghum can yield distillery products that could be used as an energy source in fish diets.

Date seed meal

With 1.5 million metric tons produced in 2016, date is another widely cultivated crop in Egypt, which is one of the world's leading countries in date production. Date cultivation occurs all over the country, but the largest proportion comes from Behera, El-Nobaria, North Sinai and New Valley governorates. Currently, the seeds are mainly used to feed large animals, like cattle, donkeys and camels, because of their appreciable fiber level. Date meal has previously been tested as a partial replacer of maize in chicken feed (El-Deek et al. 2008; El-Sheikh et al. 2013), and it might be interesting to study the incorporation of date meal in aquafeed. Its high fiber content might reduce overall digestibility, which may be mitigated through exogenous enzyme supplementation.

Tomato waste

Tomato is one of the largest vegetable crops within the country, with about 800,000 t produced in 2016 (FAOSTAT 2016). Significant amounts of tomatoes, apart from the ones directly consumed by humans, are processed into ketchup. A number of ketchup companies are situated within the country, including Heinz. These companies produced large quantities of "tomato waste," which could undergo further processing and possibly be used in fish feed. The availability of this tomato waste is usually restricted by its seasonality. The high moisture content of the products also limits its inclusion into animal feed. Tomato waste is used in ruminant feeds (Alaa Badr, Skretting Egypt, personal communication, 2017).

Sugar beet and cane pulp

Domestic sugar production is a well-established sector in Egypt, mainly from sugar cane and sugar beet crops. Over 13 million metric tons of sugar beet and 15 million metric tons of sugar cane were produced in 2016 (FAOSTAT 2016). These crops are mainly processed into sugar, for both domestic consumption and export. Cane is widely cultivated in and around Upper Egypt, preferably in February and September, while beets are mostly planted in August and September and harvested in March.

Refining both sugar cane and pulp into sugar generates large quantities of pulp that are mainly used in animal feed, particularly for ruminant animals. It is currently not used in aquafeed production, but it could in the future. Beet pul contains about 15% crude protein and 18% crude fiber (Skretting Egypt 2017).

8.3.3 Nonconventional resources available in negligible quantities

There are pockets of research on the nutritive values of some nonconventional resources produced in small amounts, including potato peels and leaves, cumin seeds, okara meal, guava by-products, jatropha seed meal, azolla meal, ulva meal, duckweed, seaweed, earthworm, maggot meal and gambusia meal.

8.3.4 Priority aquafeed ingredients for further research in Egypt

The ingredients listed in Table 32 should be considered for further research as aquafeed ingredients in Egypt. These are mainly produced locally within Egypt or could be sourced from a neighboring country.

8.3.5 Conclusions for Egypt

In Egypt, imported fishmeal and soybean meal are the main protein sources in aquafeed. This is because the local fishmeal (dry fish) is less nutritious and insufficient to meet local demand. Also, the soybean seeds locally produced are inappropriate for production of good quality soybean meal. For this reason, soybean crushers in the country are discouraged from sourcing soybean seeds within Egypt. Going forward, there is a need to work closely with soybean farmers to develop appropriate solutions necessary to improve the quality of locally produced soybean seeds. Apart from soybean and fishmeal, groundnut cake is another important protein ingredient in Egypt. Other important protein sources for fish feeds in Egypt are sesame seed meal, cotton seed meal, sunflower seed meal, shrimp meal, blood meal, feather meal and poultry. Proper availability of poultry meal, blood meal and feather meal in Egypt requires strategizing to increase collection and better processing of these resources. Azolla, duckweed and other algae are present in some parts of the country. Future research should focus on commercial production of these ingredients for aquafeed production.

Photo credit: Agboola J.O/WorldFish

Feed manufacturer's interview in Egypt.

Ingredients	Research action(s) needed
Protein sources	
Soybean meal	• Improve soybeans produced locally. (Currently, they are not good for soybean meal production, because farmers tend to harvest early, which results in greenish oil being produced after crushing, which is less preferable for consumers.) • Educate soybean farmers on proper agronomical practices for producing premium soybean seeds.
Groundnut cake	• Mainly imported from neighboring countries (e.g. Sudan). • Improve processing methods to produce high quality groundnut cake with less liability to mycotoxin contamination.
Sesame seed meal	• Further information needed on the volume available within the country.
Sunflower seed meal	• Further information needed on the available volume of sunflower seed meal for aquafeed production in Egypt.
Cotton seed meal	• Further information needed on the available volume of cotton seed meal for aquafeed production in Egypt.
Local fishmeal	• Further information needed on the volume available within the country. • Improve processing methods to increase the protein content of locally produced dry fish for aquafeed production.
Shrimp meal	• Improve processing methods to increase the protein content of locally produced shrimp meal for aquafeed production.
Blood meal	• Improve collection and processing methods to increase availability of blood meal for aquafeed.
Feather meal	• Improve collection and processing methods to increase availability of feather meal for aquafeed.
Poultry meal	• Further information needed on the available volume of poultry offal for poultry meal production. • Improve collection and processing methods to increase availability of poultry meal for aquafeed.
Energy sources	
Maize meal (yellow and white)	• Replace with quality alternatives that have less competition from humans and livestock.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Maize bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Wheat bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Beet pulp	• Further information needed on the volume available for aquafeed production. • Use processing methods to reduce the level of fiber.
Sugar cane pulp	• Further information needed on the volume available within the country. • Use processing methods to reduce the level of fibre.
Rice polishing	• Further information needed on the volume available in the country.

Table 32. Priority ingredients for consideration in aquafeeds and proposed further research to improve their nutritional quality.

9. Country review: Nigeria

9.1 Introduction

Nigeria is the most populous country in Africa, with about 180 million people and a total land area of 923,768 km^2. The country is divided into 36 states, which can be officially consolidated into six geopolitical zones as shown in Figure 19: South-South, South-West, South-East, North-East, North-Central and North-West. Nigeria has always been an "agric-centric" country, but its reliance on the agricultural sector changed after the discovery of oil in 1956. This shifted the attention of the government totally. Revenues from the sales of cash crops such as cocoa, groundnut and cotton began to decline as the country turned toward oil as its main source of foreign exchange and government revenue. However, despite the neglect of the agricultural sector, Nigeria is still predominantly an agricultural society. Agriculture accounts for about 55% of employment and 40% of total GDP (Yusuf 2014). Because of the recent meltdown in the global price of oil, the current government has re-shifted its attention toward investment in agriculture to move from being a mono-economy to having a diversified economy. The main agricultural crops produced in Nigeria are cassava, yams and maize. Other crops of importance produced in large quantities are indicated in Table 33. The distribution of these crops in the six geopolitical zones is as shown in Figure 20. Agricultural growth, in general, is constrained by poor infrastructural development, inadequate access to modern technology, high interest rates on loans and poor pricing of agricultural products.

9.2 Aquaculture in Nigeria

Fish farming in Nigeria started in 1950 or 1960, depending on the literature source (Longhurst 1961; Anetekhai et al. 2004). Until recently, capture fisheries has always been more important than aquaculture in Nigeria. Out of the 500,000 t of fish produced in 2007, 460,000 t came from capture fisheries (Ayinla 2007) and less than 50,000 t from aquaculture. However, by 2012, the aquaculture sector had grown 500% to 250,000 t (FAO 2012) The need to narrow the gap between production and demand for fish is the major driver of aquaculture growth in Nigeria. The domestic demand for fish is estimated at 1.5 million metric tons (Ayinla 2007). This, coupled with recent investments in the private

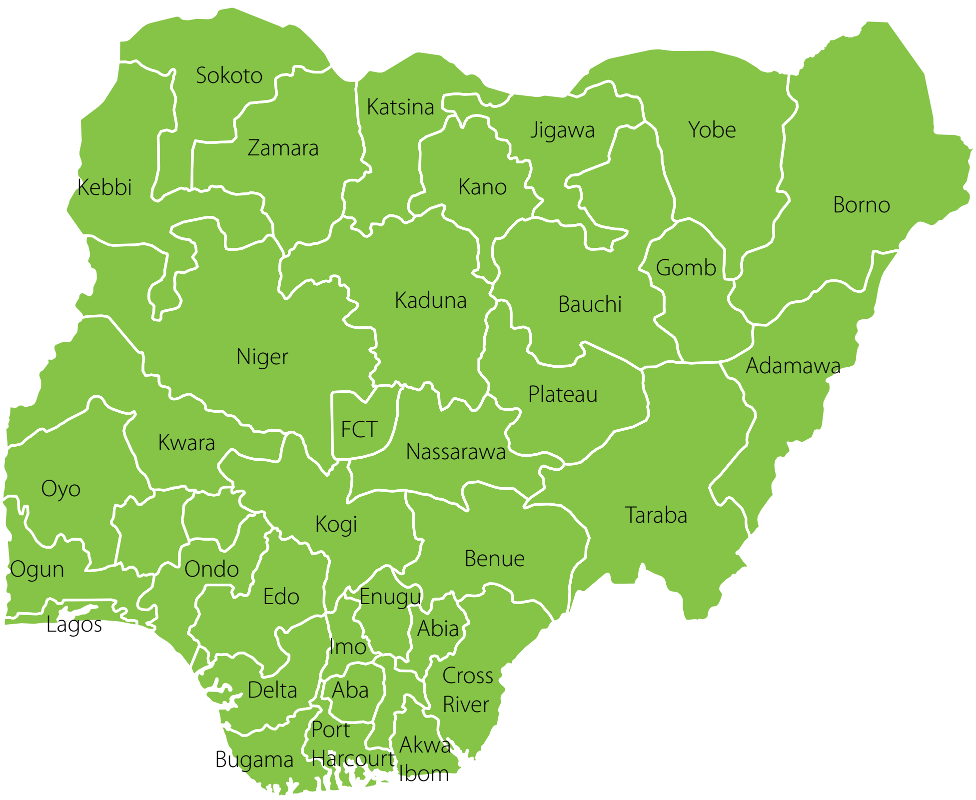
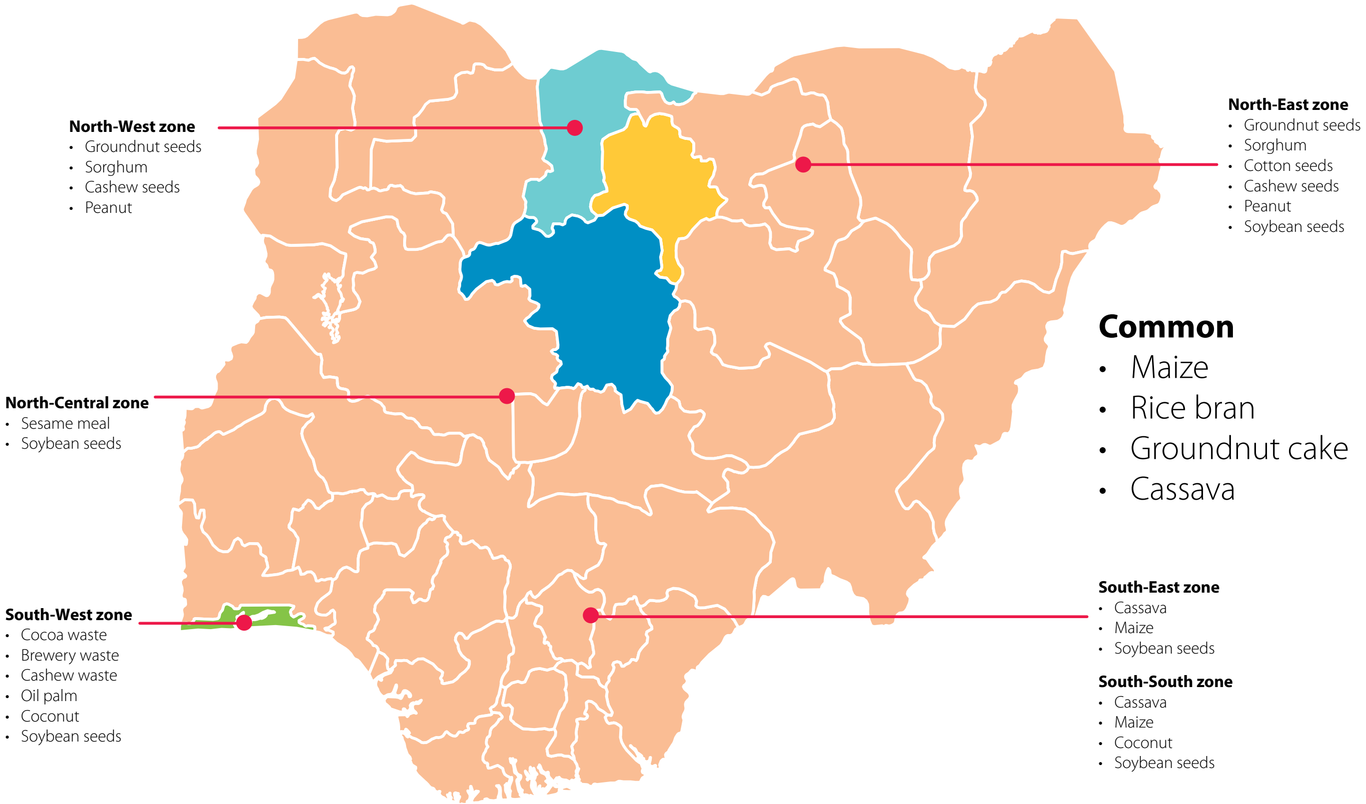


Figure 19. Geopolitical zones of Nigeria.[8]



Source: editable map from: yourfreetemplates.com

Figure 20. Distribution of crops based on geopolitical zones of Nigeria.

Crop	Yield (t)	Availability	By-products
Cassava	57,134,000	+++	Peel, leaves
Yam	44,109,000	+	Peel, leaves
Maize	10,414,000	+++	Flour, bran, gluten
Palm oil seed	7,817,000	+++	Cake, oil
Sorghum	6,939,000	+	Sorghum meal
Rice	6,070,000	+++	Bran, broken rice
Groundnut	3,413,000	+++	Cake, oil
Cowpea seed	3,027,000	++	hulls
Cocoyam (Taro)	3,175,000	+	Peel, leaves
Millet	1,468,000	++	Millet meal
Cashew nut	959,000	+	Nut reject meal
Mango	918,000	++	Kernel meal
Soybean seed	588,000	++	Meal, oil
Sesame	461,000	+	Cake, oil
Cotton seed	303,000	+	Cake, oil
Coconut seed	283,000	+++	Cake, oil
Cocoa bean	236,000	+	Cocoa reject beans
Wheat	60,000	+++	Flour, bran

Source: FAOSTAT 2016.

Table 33. Crop production in Nigeria (2016).

sector and the renewed political will to empower the private sector, are responsible for the country's position as the largest aquaculture producer in sub-Saharan Africa. Catfish production takes place in all the geopolitical areas of the country, but South-South and South-West produce the largest shares (Fagbenro, personal communication, 2017). The dominant culture system used by fish farmers is the earthen pond. Nevertheless, other production systems, such as concrete tanks and recirculation systems, do exist as well. African catfish (*Clarias gariepinus*) is the dominant fish species, with about 133,000 t cultivated in 2010, followed by tilapia with 12,000 t (Hasan and New 2013). The aquaculture practices based on farmers' financial capabilities can be classified into small-, medium- and large-scale businesses (Ayinla 2007). Small-scale fish farmers (70% of the fish farmers in the country) can either be commercial or subsistence in nature (Ayinla 2007). These range from farms with one pond of 0.05 ha to farms of several ponds with a total surface area of 1 ha (Ayinla 2007). Feeding practices of smallholder fish farmers are largely extensive or, at best, semi-intensive. Manure, particularly from chickens, is usually added to stimulate the productivity of natural biomass in the ponds. Lime is also added before fish stocking. In addition to the natural phytoplankton and zooplankton, the fish receive supplemental low quality feeds. All sorts of agricultural by-products, such as rice bran, cassava peels and wheat bran, as well as kitchen wastes, are applied when available. Aside from these, nonconventional protein sources, such as maggots and earthworms, are also used as supplementary feeds (Ayinla 2007). Stocking density ranges from 1 to 2 fish/m^2 and production from 1 to 2 t/ha/year. On the other hand, medium-scale fish farming accounts for 10%–20% of the total aquaculture production (Ayinla 2007). These businesses mainly use concrete tanks or earthen ponds for intensive catfish cultivation. In some cases, ponds are fertilized with chicken manure, but usually feeds either in the form of farm-made or complete compound feeds are given to the fish. Production levels of 4–20 t/ha/year after a culture period of 9–12 months (Ayinla 2007) are generally attained. Stocking density is also higher and ranges from 4 to 20 fish/m^2. Lastly, large-scale fish enterprises, constitute 5%–10% of total aquaculture production

Local grinder used for grinding feed ingredients.

(Ayinla 2007). Fish are mostly reared under intensive systems, with greater control of pond environmental conditions and supply of high quality diets. The ponds are usually larger than in both small- and medium-scale enterprises, covering 15 ha or more. The enterprise usually comprises 20–30 ponds (for both nursery and production ponds), a hatchery and a feed mill for feed supply (Ayinla 2007). Where there is no feed mill, the farms normally enter agreements with commercial aquafeed manufacturers for their regular supply of fish feed. The descriptions of the three production practices in Nigeria are shown in Table 34.

9.3 Status of Nigeria's aquafeed industry

The development of aquafeed in Nigeria has always been in tune with the growth of commercial fish farming. Up to the year 2000, the contribution of aquafeed to total animal feed production was negligible. An estimated 35,570 t of aquafeed were used in 2000, representing less than 1% of national feed production (Fagbenro and Adebayo 2005). Poultry feed has always been the main product, accounting for 90% of animal feed produced in Nigeria. However, in 2015 an estimated 5.3 million metric tons of feed were produced in the country, of which aquafeed contributed 12%, second behind poultry feed (Udo and Umanah 2017). The sector is dominated by large-scale commercial feed industries. Between 700,000 and 900,000 t of aquafeed are imported annually into the country, which is about 70% of the total amount aquafeed used (Udo and Umanah 2017). The imported feeds are largely high quality starter feeds needed to boost production during the early stages in the life of fish. Farmers prefer using imported starter feeds throughout the early phase (1–2 months) before switching to local feeds. During the latter phase, farmers use either on-farm feeds or commercial feeds.

Culture system	Environmental modification	Type of feeds	Species	Stocking density fish/m²	Production (t/ha/year)
Small-scale production system					
Earthen pond	Fertilization with chicken manure and liming	Household waste	Polyculture (African catfish, tilapia and African bony tongue)	1–2	1–2
Medium-scale production system					
Integrated pond culture with poultry	Paddle wheel for aeration	Farm-made pellets	Polyculture (catfish and tilapia)	10–15	10–15
Fertilized pond culture	Stagnant water in earthen pond	Farm-made pellets	Polyculture (catfish and tilapia)	5–10	5–8
Water recirculation or flow through tank culture	Concrete tanks 10–15 m³ with water flow through system	Local or imported pelleted feeds	Monoculture (catfish)	20–25	25–50
Water flow through system in earthen pond	Earthen ponds	Locally pelleted feed and fertilization with chicken manure	Monoculture (catfish)	10–15	10–12
Large-scale production system					
Water flow through system in earthen pond	Earthen ponds	Local or imported pelleted feeds	Monoculture (catfish)	10–15	10–20
Water recirculation or flow through in tank culture	Concrete tanks	Local or imported pelleted feeds	Monoculture (catfish)	20–30	10–50

Table 34. Fish production in small-, medium- and large-scale production systems in Nigeria.

Farm-made feeds accounted for 70% of total aquafeed produced in 2000 (Ibiyo and Olowosegun 2005). However, recent investments by giant feed companies like Skretting, Olam and others have tilted the scale toward more local production of commercial fish feeds. Nonetheless, some farmers still produce feeds on-farm. This is usually made of traditional feedstuff fed as blended mixtures, doughs or compressed pellets (Shipton and Hasan 2013). The quality of farm-made feeds depends on the method of formulation, ingredient quality and the manufacturing processes (Udo and Umanah 2017), the latter of which have been well documented by Ayinla (2007).

In brief, the ingredients are first cooked or heated to destroy any antinutritional factors and to improve digestibility. The ingredients are milled, then compounded and mixed, either manually or with the aid of simple mechanical mixers. Next, hot water is added and the mixture is kneaded into dough. Cassava or maize starch is usually added as a binder. The dough is then passed through a meat mincer or perforated metal sheets to form moist spaghetti-like strands. These are either fed directly to the fish or sun dried on corrugated iron sheets, jute bags or using homemade electric dryers.

9.4 Aquafeed resources in Nigeria

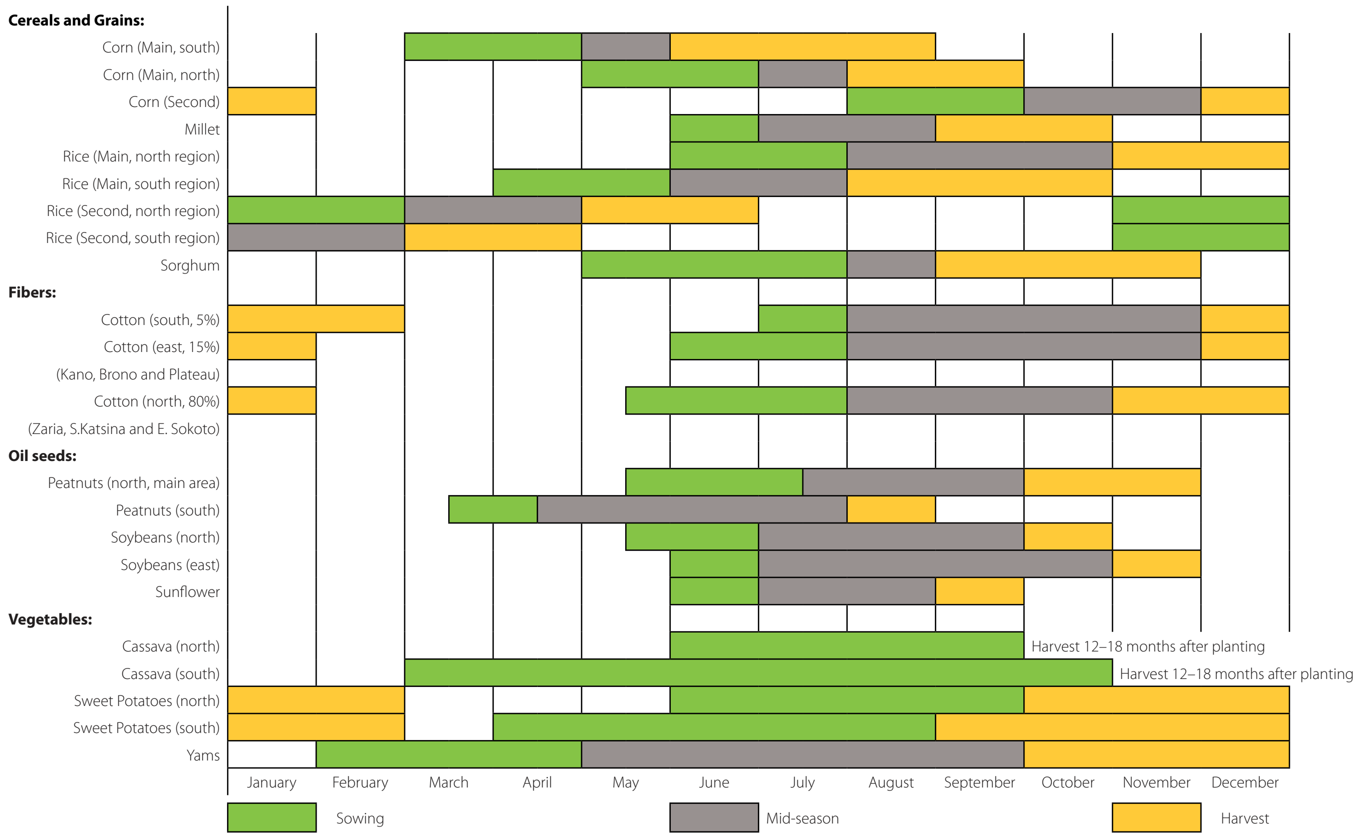
The ingredients most commonly used in aquafeed and those with potential to be used are described in Table 35 and their nutritional composition is shown in Table 36.

9.4.1 Current feed ingredients used in Nigeria

9.4.1.1 Protein sources: Plant origin

Soybean meal

Soybean meal is the most important plant protein source used for commercial feed production in Nigeria. In 2003, the local production of 255,000 t was far below the required 750,000 t (Fagbenro et al. 2003). Soybean seeds are dominantly produced in Benue State in the North-Central part of the country. Other major producing states are Kaduna, Plateau, Nassarawa and Oyo. Soybean cultivation usually starts in May/June and harvesting normally occurs in October/November (Figure 21). There is a paucity of information on the current volume of soybean meal produced in the country, but in 2016 there were 588,000 t of soybean seeds produced, which was sufficient to meet the local demand, for both food and feed (Indexmundi 2017). Aquafeeds compete with livestock feeds for use of soybean meal, and the biggest user is the poultry feed industry, which accounts for nearly half of soybean meal used in Nigeria.



Source: USDA.

Figure 21. Crop calendar of Nigeria.

Ingredient	Currently used in aquafeeds	Source
White maize meal	Yes	Local
Yellow maize meal	Yes	Local
Maize bran	Yes	Local
Millet meal	No	Local
Wheat meal	Yes	Local
Wheat bran	Yes	Local
Rice bran	Yes	Local
Sorghum	No	Local
Sorghum bran	No	Local
Cocoa oil cake	No	Local
Cocoa pods (dried)	No	Local
Coconut/copra cake	No	Local
Dried coconut kernel	No	Local
Cotton seed cake	Yes	Local
Sesame seed cake	No	Local
Cassava peel	Yes	Local
Cassava leaf	No	Local
Groundnut seed cake	Yes	Local
Beet pulp	No	Local
Brewers' dried grain	No	Local
Distiller dried grain with soluble	Yes	Imported
Palm kernel cake	No	Local
Sugar cane pulp	No	Local
Blood meal	Yes	Local
Fishmeal	Yes	Local and imported
Feather meal	Yes	Local
Shrimp meal	No	Local
Poultry meal	Yes	Local and imported
Crab meal	No	Local
Crayfish meal	No	Local
Maggot meal	Yes	Local
Earthworm meal	No	Local
Leucaena leaf meal	No	Local
Mango kernel meal	No	Local
Mucuna seed meal	No	Local
Cocoa reject meal	No	Local
Noodles and biscuit waste	Yes	Local
Cowpea seed meal	No	Local
Cashew reject meal	No	Local
Yam peels	No	Local
Taro leaf and peel	No	Local
Mango kernel meal	No	Local

Table 35. Available ingredients (both plant and animal origin) for aquafeed production in Nigeria.

Ingredient	DM	CP	lipids	CF	Ash	NFE
Cereals/by-products						
White maize	91.4	9.3	5.0	2.4	1.7	81.6
Yellow maize	90.4	10.1	3.56	3.5	1.9	80.94
Millet	91.3	4.8	1.3	38.3	5.7	49.9
Rice bran	89.5	12.3	2.1	14.6	12.6	58.4
Sorghum	88.0	7.8	4.8	7.6	2.1	77.7
Sorghum bran	94.0	3.8	8.7	12.1	2.7	72.7
Oil seeds/by-products						
Cocoa oil cake	88.6	23.1	5.3	8.9	5.3	57.4
Cocoa pod (dried)	88.5	5.8	0.7	21.5	7.6	64.4
Coconut cake	92.0	20.0	6.3	12.0	7.0	54.7
Coconut kernel (dried)	96.0	7.2	64.6	3.8	1.9	22.5
Cotton seed cake	92.5	50.0	1.6	8.2	6.5	33.7
Cotton seed	92.1	20.4	20.0	21.1	4.3	34.2
Groundnut seed	93.5	28.4	44.7	2.2	2.3	22.4
Groundnut seed cake	90.4	46.2	6.9	7.5	5.2	34.2
Palm kernel cake	-	18.0	6.0	42.0	0.21	33.79
Animal protein sources						
Blood meal	89.6	81.5	1.0	0.7	4.8	12.0
Fishmeal	93.0	59.0	6.9	0.8	21.9	11.4
Feather meal	91.9	84.2	2.8	0.5	3.4	9.1
Poultry meal	91.7	61.6	16.5	3.5	9.0	9.4
Nonconventional resources						
Crab meal	90.9	31.7	2.4	-	46.2	19.7
Crayfish meal	85.0	41.2	11.7	-	31.7	15.4
Maggot	90.7	43.8	1.9	14.3	14.3	25.7
Earthworm	95.0	56.4	7.8	1.6	8.8	25.4
Leucaena leaf meal	-	29.6	5.3	18.8	4.4	41.9
Mango kernel meal	-	7.5	7.3	2.0	2.6	80.6
Mucuna seed meal	-	32.1	4.6	6.9	2.3	54.1

Source: adapted from Ogugua and Eyo 2007.

Table 36. Percentage nutritional composition of aquafeed ingredients used in Nigeria.

Groundnut cake

Groundnut cake is another widely used plant protein source for aquafeed. Nigeria is the largest producer in Africa and is a dominant force in groundnut production throughout the world. Before the discovery of oil, groundnut was once the country's most important export crop. In 2016, annual groundnut production was 3.4 million metric tons (FAOSTAT 2016), from which about 750,000 t of cake was produced for domestic animal feed production (Indexmundi 2017). Groundnut is widely grown in the North-Western, North-Eastern and North-Central parts of the country, mostly from the end of June until December (Figure 21), and there is intense competition between poultry feeds, aquafeed and humans for groundnut. Groundnut meal is vulnerable to mycotoxin contamination, especially aflatoxin, which is a major concern for its incorporation into animal feed.

Cotton seed cake

Cotton seed cake is mainly used as a protein source in fish feed, mostly in combination with fishmeal or any other plant protein source, such as groundnut cake and soybean meal. Cotton seed cake is relatively low in cystine, methionine and lysine as well as calcium (Eyo 2003), so when it is used as the only protein source in aquafeed, adequate supplementation with synthetic amino acids is needed to offset the deficiency in amino acids. In 2016, local production of cotton seeds was about 300,000 t, the majority of which were produced in the northern part of the country. In 2005, the annual processing capacity was 520,160 t (Ayinla 2007). Nigeria exports cotton oil seed cake mainly to Egypt and South Africa (Fagbenro et al. 2003).

Sesame seed cake

In spite of its nutritional value, sesame seed cake is only used in small proportions in aquafeed, mainly by small-scale producers, especially in the northern part of the country, where it is widely cultivated. Annual production currently stands at 400,000 t (Table 33). The cake contains 35%–40% protein and is high in methionine and tryptophan, though limited in lysine (Ayinla 2007). The cake is devoid of any antinutritional factors, and it is rich in linoleic acid as well as vitamins (vitamin A, B, B2, E) and it also contains niacin, which is lacking in soybean meal (Ayinla 2007). Sesame is widely used in human food, which is why it is available only in limited quantities for animal feed production.

Palm kernel cake

Nigeria is the frontrunner of palm oil production in Africa and the fourth-largest producer in the world. Current local production of palm nuts stands at 7.8 million metric tons per year (FAOSTAT 2016). There is no current record about the quantity of palm kernel cake generated in the country, but over 400,000 t were manufactured in 2000. Considering that local production and consumption of palm oil has rapidly increased over the past 15 years, it is safe to assume that the current quantity of palm kernel cake has increased dramatically over this particular period. Palm oil seeds are widely grown in the southern part of the country (South-West, South-East and South-South). Palm kernel cake has low nutritional value for monogastric animals (Fagbenro and Adebayo 2005) because of its high lipid content, so it is mostly used in feeding large animals, such as cattle and goats, and in fattening pigs. Nevertheless, palm kernel cake is used by small-scale fish producers. The inclusion rate in fish diets is less than 10% because of its high fiber content (Ayinla 2007).

9.4.1.2 Protein sources: Animal origin

Fishmeal

Nigeria heavily depends on importing fishmeal from Norway and Denmark to meet its animal feed requirements. Between 80% and 90% of the fish derived from both artisanal and industrial marine and inland fisheries are used for human consumption (Ayinla 2007). The latter author further hinted that the remainder (10%–20%), as well as the fish offal (heads and tails), from processing factories and discarded fish is processed into fishmeal. In 2000, local fishmeal production was estimated at 8050 t, but no recent data is available (Fagbenro and Adebayo 2005). This was produced by only one operational commercial fishmeal processing plant, which has since closed down because the cost of local fishmeal was higher than imported ones. Ayinla (2007) reported that in 2004 the cost of imported fishmeal ranged from USD 870 to 1350/t, while the cost of locally produced fishmeal was USD 1500. Currently, all fishmeal used in commercial feed production in Nigeria is imported. Nigeria can invest in fishmeal manufacturing plants to explore unexploited fish resources in national waters, but a comprehensive stock assessment of the resource and overall cost effectiveness of the entire process is needed (Fagbenro and Adebayo 2005; Ayinla 2007).

Feather meal

The Poultry Association of Nigeria estimated that local poultry production was 708,000 t in 2011. More recent data is not available, but it is assumed that production increased further because of the recent development in the sector. The local production of hydrolyzed feather meal in Nigeria was 19,000 t in 2000 (Fagbenro and Adebayo 2005), but this is expected to have increased in accordance with the rise in the number of poultry produced in the country. Using the widely known conversion factor that feathers accounted for roughly 7% of the live weight of poultry birds, 50,000 t of feather meal were manufactured in Nigeria in 2011. Feather meal is used mainly for poultry feed production, which affects its availability for fish feed manufacturing. Currently, there is under-exploitation of this resource in Nigeria, with only few rendering plants in the country.

Blood meal

Blood is an important by-product from abattoirs. Approximately 55,000 t of blood meal were locally generated in 2000 (Fagbenro and Adebayo 2005). Blood meal is relatively high in protein (80%), but the heat used during the local processing affects lysine availability (Ayinla 2007). Local blood meal is also deficient in isoleucine, cystine and tryptophan (Eyo 2003), so it must be supplemented with synthetic amino acids in aquafeeds. There is a restriction to use this resource in Nigeria because of the associated cultural, religious and social taboos (Fagbenro and Adebayo 2005). Therefore, in most cases, blood meal is immediately recycled and used in farm-made feeds for pigs and fish. This is mostly restricted to small-scale farmers in rural areas. Aside from the sociocultural bias, unavailability of rendering facilities is another limiting factor toward the use of this resource.

Poultry meal

With enormous amounts of poultry "waste" in the form of offal and other inedible parts constantly available, annual local production of poultry meal is about 24,000 t (Fagbenro and Adebayo 2005). The largest share of this meal goes to poultry feed. Backyard fish farmers sometimes incorporate it as part of kitchen waste (household waste) to stimulate natural food production in ponds. Only a little proportion of the total poultry waste is currently processed into meal, so there is room for better exploitation of this valuable feedstuff for aquafeed production.

Shrimp head meal

Nigerian shrimp is an export-oriented sector, with an annual production of 72,000 t (Fagbenro and Adebayo 2005). Shrimp are caught in the coastal areas of the country, then processed and packed for export, which generates about USD 2.4 million in revenue for the government (Fagbenro and Adebayo 2005). The heads and shells are dried and milled and then used as an ingredients for fish feeds, particularly in the coastal states (Ayinla 2007). Approximately 34,000 t (24,000 t for heads and 10,000 t for shells) of shrimp waste are generated annually, of which 9000 t of dry shrimp meal are annually manufactured (Fagbenro and Adebayo 2005). In fish production, shrimp meal is primarily used as an attractant rather than a protein source (Ayinla 2007).

9.4.1.3 Energy and fiber sources: Plant origin

Maize and maize bran

Maize is an important staple food and one of the most commonly produced crops in Nigeria. The production of maize, both yellow and white, occurs in all parts of the country. In 2016, local maize production was 10.4 million metric tons (FAOSTAT 2016). Maize is mainly used as an energy source in animal feed production. The biggest consumer of maize in Nigeria, apart from humans, is the poultry sector, and this limits the availability of maize for aquafeed. There is quite a number of flour mills in Nigeria, and these factories generate large quantities of maize bran, which is readily available for both poultry and aquafeed production. Although maize bran contains relative amounts of energy, it also has considerable fiber content that limits its inclusion rates in aquafeed.

Cassava peel and leaf

Cassava is another major staple food in Nigeria, which is the largest producer in the world, with over 57 million metric tons manufactured in 2016 (FAOSTAT 2016). The root is widely produced in the southern part of the country. Cassava is processed into different kinds of foods, from which several by-products, such as the peels, leaves, the pomace (from starch) and *garri* (cassava flour) are produced in large quantities and considered as animal feed resources. There is no recent data on the quantity of cassava by-products generated, but about 5 million metric tons were said to be generated in 2000 (Fagbenro and Adebayo 2005). The peels are mainly fibrous in nature, considered a low value feed ingredient used for ruminants, so it is widely disposed indiscriminately into the environment. On the other hand, the leaves contain relatively high amounts of protein, though this is rarely included in aquafeed. In addition, *garri* is primarily used as a starch source and secondarily as a binder in farm-made feeds.

Brewery by-products

There are a number of brewery factories, both government- and privately owned, in Nigeria. These companies produce large quantities of by-products that could potentially be incorporated into aquafeed. The most valuable by-products of the brewery industry are brewers' dried grain, wet waste and maize grits (Ayinla 2007). Brewers' dried grain is the extracted residue of fermented barley or barley mixed with other grains. In 2000, there were 286,000 t of distiller dried grain produced locally in Nigeria (Fagbenro and Adebayo 2005). It is low in energy but high in fiber, so it is included in fish feeds at 5% or lower, while a large proportion of it is used in feeding cattle and pigs. Maize grit, on the other hand, is the medium-sized, hard, flinty portions of ground maize containing little or none of the bran or germ (Ayinla 2007) and is mostly produced as by-products of malt production.

Rice bran and broken rice

Rice is a ubiquitous staple food that is widely cultivated in every part of the country and consumed by every household in Nigeria. Sowing starts in March/April and harvesting occurs from October until the end of the year. In 2016, 6 million metric tons of rice were produced (FAOSTAT 2016), but this falls short of the domestic demand for rice. There are rice milling factories in the country, and the production of rice normally comes with large quantities of by-products that are used in livestock feed. First on this list is rice bran, which is predominantly included in both aquafeed and poultry feed. Rice bran is widely available and can be used as an energy source, but its high fiber content limits its inclusion rates in fish feed. Approximately 390,000 t of rice bran were locally produced in 2000 (Fagbenro and Adebayo 2005), but no recent data is available. Broken rice is another by-product that can be incorporated in aquafeed. Local production of this was about 17,000 t in 2000 (Fagbenro and Adebayo 2005). It is mostly unavailable for commercial feed manufacturers, but small-scale producers sometimes include it in their diet formulation.

Wheat and wheat offal

Wheat is another widely consumed staple food in Nigeria and is produced throughout the country. Local production of wheat is about 60,000 t per annum, from which over 25,000 t of wheat offal are generated (Fagbenro and Adebayo 2005). Because of the feed-food competition for wheat, wheat offal is the one most used in animal feed. Poultry feed offers the greatest competition to its availability in aquafeed. Wheat bran is high in fiber, which restricts its inclusion levels in aquafeed.

Sun drying farm-made spaghetti-like pellets on jute bags.

9.4.1.4 Oil and fats

The oils used in aquafeed production are listed in Table 37. Maize oil is the most commonly used for commercial fish feed production.

9.4.2 Potential feed ingredients in Nigeria: Protein sources

Coconut meal

Coconut oil is largely used in Nigeria because of its widespread health benefits. The oil is used in the industrial production of soap, hair cream, etc., and is traditionally used as skin softener. The coconut oil is normally extracted from the kernel of mature coconuts, which simultaneously produces residues known as copra or coconut meal that can be used as protein in animal feed, including fish feed production. Local production of coconut oil currently stands at 280,000 t (FAOSTAT 2016), from which 4000 t of copra meal are currently generated (Indexmundi 2017). Coconut production is better in the southern part of the country compared to the northern.

Cocoa reject meal

Cocoa production is very important as a source of foreign exchange currency for Nigeria, which is currently the fourth-largest producer and the third-largest exporter worldwide. Cocoa is largely grown in southern Nigeria, with 236,000 t produced in 2016 (FAOSTAT 2015). The ungraded pods, which are not fit for export, are readily available and could be used in aquafeed.

Noodles and biscuit waste

There is no quantitative data on the availability of noodles or biscuit waste in Nigeria. The variability of nutrients in noodle and biscuit waste depends on the composition of the final products. For example, the crude protein content of noodle waste varies from 10% to 35% (Agbebi et al. 2013; Omole et al. 2013). These authors have hinted that it can be used as an alternative to maize in both catfish and broiler chicken feed. Currently, these two ingredients are not commercially used in animal feed. However, the number of Nigerian companies involved in noodle and/or biscuit production is enough to delve into the possibility of including these in commercial aquafeed production. Olam currently uses biscuit waste in animal feed.

Cashew reject meal

Cashew is one of the major fruit crops produced in Nigeria, with 950,000 t of cashew nuts produced in 2016 (FAOSTAT 2016), mainly in the southern part of the country. The nuts are processed and used for human consumption, but rejected nuts, which are not fit for human consumption, can be incorporated into animal feed. Processing cashew nuts into secondary products also generates by-products such as cashew oil and cashew cake, which may be suitable for fish feed. The nutritional value of cashew reject meal has been explored in previous experiments (Odunsi 2002; Akande et al. 2015). The nutritional composition of the meal depends on the degree of oil remaining in the nuts. Therefore, the crude protein content ranges from 22% to 35%.

9.4.2.1 Other nutrient sources

Sorghum

Local production of sorghum is restricted to the northern part of Nigeria. It is mainly part of local delicacies but can be used as an alternative to maize as an energy source in aquafeed. About 6.9 million metric tons of sorghum were generated in 2016 (FAOSTAT 2016), which were largely used for

Name	Source	Availability
Fish oil	Imported	Scarce
Palm oil	Local	Adequate
Groundnut oil	Local	Adequate
Soybean oil	Local	Adequate
Coconut oil	Local	Scarce
Maize oil	Local	Scarce
Olive oil	Imported	Scarce
Vegetable oil	Local	Low

Source: Fagbenro and Adebayo 2005.

Table 37. Oils used for aquafeed production in Nigeria.

human consumption. The bran is mainly included in animal feeds. Fagbenro and Adebayo (2005) stated that about 190,000 t of sorghum bran were locally generated and included in both poultry and aquafeed production. Like every other bran from cereals, sorghum bran is very high in fiber.

Millet

Millet is another ingredient that can be used as alternative to maize as an energy source in aquafeed. The grain is cultivated throughout the country, but it is more dominant in the northern part. Annual millet production currently stands at over 1.4 million metric tons (FAOSTAT 2016), mostly for human consumption, which is substantially lower than the 6.2 million metric tons produced in 2000 (Fagbenro and Adebayo 2005).

Cowpea seeds

Cowpea seeds are a valuable plant protein source in the diet of Nigerians. The legume is widely cultivated throughout the country, but larger production comes from the northern part, especially in states like Niger, Sokoto, Kebbi, Zamfara, Kaduna, Kano and Gombe. The seeds are unavailable for livestock feed, but the hulls are used in it, particularly in ruminant diets. Data on the available quantity is scarce, but about 3 million metric tons of cowpea seeds are locally manufactured annually, so it can be assumed that cowpea seed hulls are widely available in the country. The potential for aquafeed remains unexplored, so future efforts should focus on the possibility of incorporating seed hulls into fish feed production.

Taro leaves and peels

Cocoyam is a tuber crop mainly produced and consumed in southern Nigeria, with 3 million metric tons produced yearly (FAOSTAT 2016). This production comes with by-products, such as leaves and peels, that can be considered for use in aquafeed.

Yam peels

Yam is the largest cultivated tuber crop in Nigeria. Cultivation starts in February, at the onset of rainfall, and harvest runs from November to December. Yam is produced predominantly in the southern region, and some parts of the North-Central, particularly Benue State. In 2016, Nigerian yam production was over 44 million metric tons, producing large amounts of leaves and peels. The peel is used for feeding ruminant animals, particularly goats, by backyard animal owners. Commercial use of peels or leaves in either livestock or aquafeed production is currently nonexistent, because the peel is relatively low protein, though it is high in fiber.

Mango kernel meal

Mango is another economically important fruit crop in Nigeria, with over 900,000 t produced annually (FAOSTAT 2016). Mango is mainly used for human purposes, especially mango juice in the canning industry, but the kernel can be processed into meal and used in animal feed. Mango kernel meal is currently not used in aquafeed. Some authors report its nutritional potential as an alternative to maize for chicken feed (Odunsi 2005; Diarra and Usman 2008). It contains about 10% crude protein (Fowomola 2010).

9.4.3 Nonconventional resources available in Nigeria

Apart from the above feed ingredients, there are other cheaper resources, not available for human consumption, which have been previously characterized, explored and investigated as fish feed ingredients. Some of these nonconventional fish feed ingredients of plant origin are mucuna seed meal, jack bean, pigeon peal, winged bean, sesbania, leucania, ipil ipil and locust bean. Those of animal origin are maggots, earthworms, toad meal, rumen epithelial scrapings, crab meal and crayfish meal. The use of these nonconventional feed ingredients is limited by their availability in the market, because they are not readily available in commercial quantities for large-scale fish feed production.

9.4.4 Priority aquafeed ingredients for further research in Nigeria

Ingredient	Research action(s) needed
Protein sources	
Fishmeal	• Further information needed on the volume of local fishmeal produced within the country. • Improve processing methods to increase the protein content of locally produced fishmeal compared with conventional fishmeal (imported from Peru/Denmark).
Palm kernel cake	• Improve processing methods to decrease the lipid and fiber content in local palm kernel cake. • Improve processing methods to increase the protein content in local palm kernel cake.
Soybean meal	• Further information needed on the volume available within the country. • Include alternative protein sources to augment the use of locally produced soybean meal.
Copra/coconut cake	• Further information needed on the available volume of copra meal in Nigeria.
Groundnut cake	• Further information needed on available volume within the country. • Improve processing methods to decrease the amount of mycotoxin present in locally produced groundnut cake.
Cassava leaf protein	• Further information needed on the volume available within the country. • Organize logistics around the collection of cassava leaves for the production of cassava leaf protein.
Brewers' dried grain	• Further information needed on the volume available within the country. • Improve processing methods to increase the level of protein present in brewers' dried grain.
Sesame seed cake	• Further information needed on the volume available within the country.
Noodles and biscuit waste	• Organize the logistics around the collection of noodles and biscuit waste from producing companies.
Feather meal	• Improve collection and processing methods to increase availability of feather meal for aquafeed.
Blood meal	• Improve collection and processing methods to increase availability of blood meal for aquafeed.
Maggot meal	• Create commercial production of maggot meal for use in aquafeed.
Shrimp meal	• Further information needed on the quantities available in Nigeria.
Poultry meal	• Organize logistics around the collection of poultry offal for use in poultry meal production. • Set up a rendering facility for commercial production of poultry meal.
Energy sources	
Maize meal	• Replace with quality alternatives that have less or little competition with humans and livestock.
Maize bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Cassava peel	• Increase the inclusion level through appropriate research without compromising fish growth. • Investigate the use of cassava peels in fish diets. • Improve processing methods to decrease the fiber content of cassava peel.
Sorghum and sorghum bran	• Increase information on the quantities available for aquafeed production.
Wheat meal	• Replace with quality alternatives that have less or little competition with humans and livestock.
Wheat bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Beet pulp	• Further information needed on the quantities available within the country.
Sugar cane pulp	• Further information needed on the quantities available within the country.
Taro leaf and peel	• Further information needed on the quantities available within the country.

Table 38. Priority ingredients to be considered for aquafeed, with proposed further research to improve their nutritional quality.

9.4.5 Conclusions for Nigeria

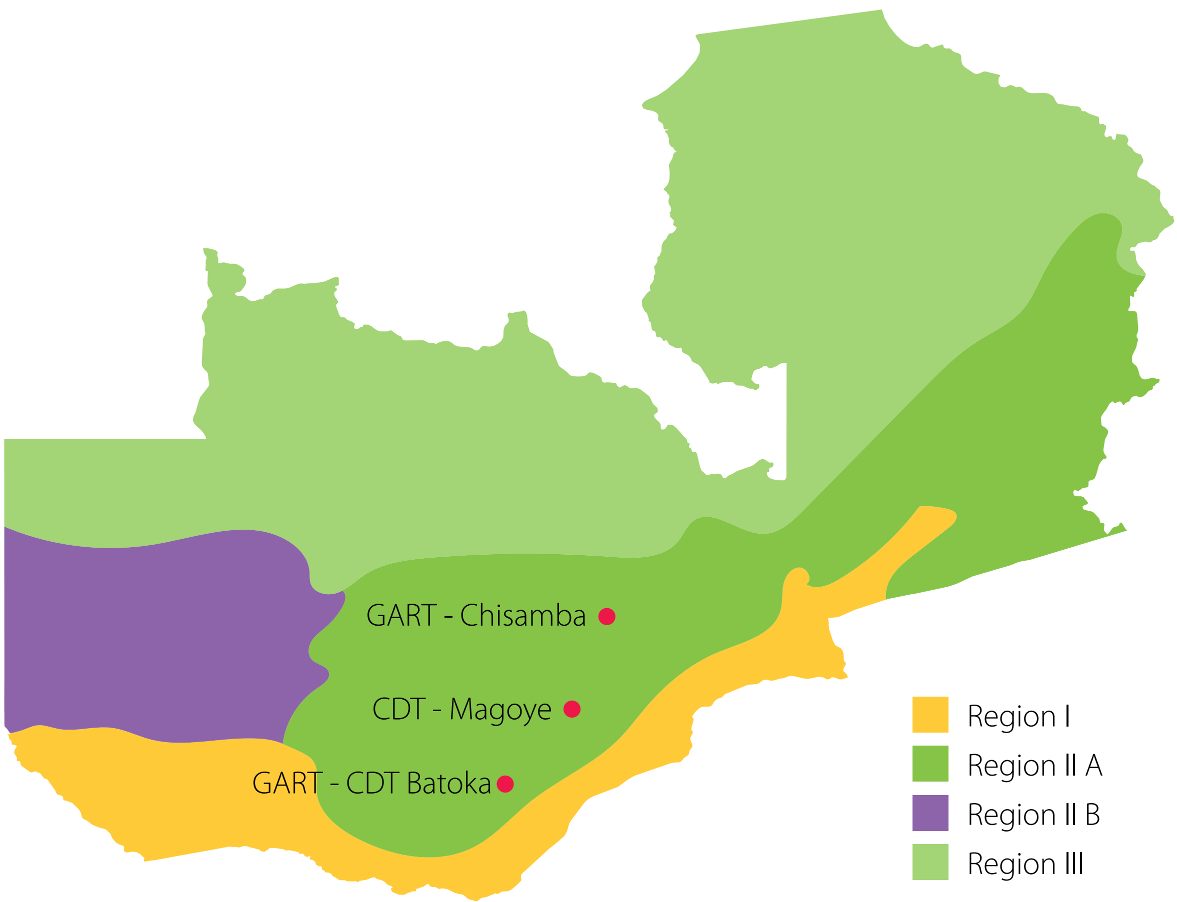
Nigeria is an agricultural producing country, and ingredients of plant origin are largely available within the country. Recently, the country's soybean production has kept up with local demand. Soybean seed is the most significant plant protein ingredient for aquafeed in Nigeria. Copra cake, groundnut cake, brewers' dried grain, palm kernel cake and sesame seed cake are other plant protein sources for aquafeed. Maize meal, maize bran, wheat bran, rice bran and, recently, cassava peels are the most common energy sources of plant origin. For ingredients of animal origin, local fishmeal (dry fish) is of lesser quality and insufficient to meet local demand for feed production. Other animal protein ingredients, such as feather meal, poultry meal, blood meal, maggot meal and shrimp meal, are currently underused. In the future, substantial efforts should be geared toward organizing the logistics surrounding the collection of these resources to increase their availability within the country. Additionally, agro-industrial by-products, such as beet pulp, sugar cane pulp, cocoa reject meal, mango kernel meal, cashew reject meal, may be considered for aquafeed production.

Heaps of cassava peels at a Garri processing factory in Oyo state.

10. Country review: Zambia

10.1 Introduction

Zambia is a landlocked country located in the southern part of Africa. It has a total surface area of 752,610 km^2, of which 743,398 km^2 are land and 9220 km^2 are water. The presence of suitable fertile lands, many lakes (Lake Kariba, Lake Bangweulu, Lake Mweru, Lake Tangnyinka), two major rivers (Congo and Zambezi) as well as a favorable tropical climate provide good environmental conditions for agriculture and aquaculture. Zambia is a member of two major African trade organizations: the Common Market for Eastern and Southern Africa, and the Southern African Development Community. These two organizations allow free trade and open access to all members, which eases imports and exports, despite being landlocked. Zambia is endowed with vast land resources of about 42 million ha, though only 1.5 million ha is cultivated (ZDA 2011). The agriculture sector is the mainstay of the economy, as it contributes 20% to GDP and 10% of the country's total export earnings (ZDA 2011). Approximately 70% of the entire population is engaged in agriculture, and as such the Zambian government has paid a good deal of attention to the development of the sector (ZDA 2011). Zambia is known as a "maize-oriented" nation because of the strong attention given to maize, whereas other crops, livestock and fish production have been neglected over the past decades (Steve Cole, personal communication, 2018). Nonetheless, the priority crops for the country are wheat, sugar, cotton, tobacco, coffee, tea and maize. Other minor agricultural commodities are cowpea, groundnut, cassava, rice, sorghum, soybean and sunflower. These crops perform very well in the different agro-ecological zones, partitioned as Regions I, II and III, which are primarily based on rainfall characteristics as a key pattern of climatic differences in these areas. The different agro-ecological zones are depicted in Figure 22.



Source: The Zambian agropreneur.

Figure 22. Agro-ecological zones in Zambia.

Comprehensive description of these regions, according to the Zambia Development Agency (ZDA) 2011, are as follows:

Region I, which has the least amount of rainfall among the three regions, covers Southern, Eastern and Western provinces. It covers about 12% of the country's total land mass, mostly with clayey or loamy soil that supports the cultivation of crops such as cotton, sesame, sorghum, groundnuts, beans and cassava.

Region II is partitioned into two, IIa and IIb, covering Central and Lusaka provinces, parts of Eastern and Southern provinces as well as Western Province. The region has intermediate rainfall with fertile soil and supports the cultivation of a number of crops, namely maize, cotton, tobacco, soybeans, groundnuts, cashew, rice, cassava and vegetables.

Region III has the highest rainfall, at 1000–1500 mm per year, and makes up 46% of Zambia's total landmass. This region covers Copperbelt, Luapula, Northern, Muchinga and North-Western provinces and has quality fertile soils suitable for cassava, sorghum, beans, sugarcane and rice production. Table 39 shows the quantity of major Zambian crops produced in 2016.

10.2 Aquaculture in Zambia

Aquaculture in Zambia was introduced over 50 years ago, when the government conducted fish farming trials and set up aquaculture research stations in the 1960s (Kaminski et al. 2017). However, only around the 1990s did commercial aquaculture begin after the successful introduction of intensive and market-oriented cage aquaculture on Lake Kariba (Kaminski et al. 2017). Until recently, the aquaculture sector in Zambia had been dominated by small-scale subsistence farming with minimal aggregated impact on total fish supply for ordinary consumers (Genschick et al. 2017). Recent growth in large-scale commercial aquaculture increased the volume of farmed fish in the past few years. Between 2012 and 2013, aquaculture production increased from 13,000 t to more than 20,000 t (DOF 2015). Currently, large-scale commercial aquaculture accounts for 71% of total aquaculture production, representing a shift from what was happening fewer than 10 years ago, when the small-scale sector contributed about 75% of aquaculture production in Zambia (Genschick et al. 2017). The commercial aquaculture sector is mainly situated around Lusaka and Southern provinces. The siting and choice of location is determined by various interrelated factors, such as climatic conditions (higher temperatures, longer dry

Ingredient	Yield (t)	Availability	By-products
Sugar cane	4,285,000	+	Cane pulp
Maize	2,872,000	+++	Bran, flour
Cassava	1,010,000	+++	Leaves, peels
Sweet potato	231,000	+	Leaves, peels
Wheat	160,000	++	Bran, flour
Groundnut	158,000	++	Cake, oil
Tobacco	124,000	+	Tobacco oil meal
Cotton seed	111,000	+	Meal, oil
Sunflower seed	61,000	+	Cake and oil
Millet	30,000	+	Flour
Soybean	27,000	++	Meal, oil
Rice	27,000	+	Bran
Tomato	26,000	+	Tomato waste
Sorghum	14,000	+	Flour, gluten, brewery dried grain

Source: FAOSTAT 2016.[9]

Table 39. Crop production in Zambia (2016).

season), year-round access to water (Lake Kariba, Kafue River), proximity to markets and a "tolerance" for using nonnative Nile tilapia (*Oreochromis niloticus*) (Sven Genshick and Steve Cole, personal communication, 2018). In other regions, the species is prohibited as per the Fisheries Act No. 22 of 2011 (Kaminski et al. 2017). Commercial cage culture is mainly situated around Lake Kariba, and land-based pond farmers are located in the Kafue flats and Copperbelt Province. The Zambian aquaculture sector is dominated by a few large-scale players: Kariba Harvest and Yalelo for cage culture, and Kafue Fisheries, Kalimba Farms, Nsobe Farms and Macademia Farms as medium- to large-scale land-based pond producers. The typology of Zambia's aquaculture system is similar to other African countries. See Genschick et al. (2017) for comprehensive information of the different aquaculture systems in Zambia.

10.3 Status of the aquafeed industry in Zambia

In Zambia, feeding and fertilization regimes in rural areas (small-scale farmers) can be categorized into three different technologies: fertilization/manuring, on-farm feed production and commercial feed application (Genschick et al. 2017). Some farmers exclusively fertilized their ponds with animal manure to stimulate the growth of natural food webs within the pond (phytoplankton and zooplankton) as fish feed. Others depend on the production of farm-made feed from locally available products, while some apply commercial aquafeed depending on the size and financial means of the farmers. It is worth mentioning that farms do combine the three aforesaid feeding regimes (Genschick et al. 2017). The development of a commercial aquafeed sector mirrors the recent development in Zambian aquaculture. Nonetheless, the development of the sector is still in a nascent phase compared to the poultry feed sector.

The sector has witnessed tremendous improvements over the past few years as a result of massive investments in commercial aquafeed production from existing feed mills and because of new entrants into the sector. Established feed mills such as Savanna Streams, Farm Feeds, Olympic Millings, Novatek Animal Feeds and Tiger Feeds, which previously produced mainly types of livestock feed, have started to diversify their product portfolio and develop lines for aquafeed manufacturing (Genschick et al. 2017). These companies combined produced 30,000 t of aquafeed in 2015 (Kaminski et al. 2017). In 2017, the two largest cage culture producers, Lake Harvest and Yalelo, ventured into partnership with Skretting and Aller Aqua, respectively. This will rapidly increase the volume of aquafeed produced in Zambia, and as a consequence an estimated additional 75,000 t of aquafeed were expected from these two companies by the end of 2017 (Genschick et al. 2017). These companies can still increase their current production, which would significantly reshape the status of the Zambian

Commercial land-based pond culture in Kafue, Kafue Fisheries.

aquafeed industry as well, with the expected rise in aquaculture production. Of significant risk to the growth of the aquafeed feed sector is the dependency on imports for supplying fishmeal and micro-ingredients, such as premixes and vitamins. However, the country is doing well in regards to its supply of plant feed resources, as the majority of such macro-ingredients are sourced domestically. On the other hand, there is significant opportunity for aquafeed companies to export to neighboring countries. Further information on the existing and potential aquafeed ingredients in Zambia is discussed in the next section.

10.4 Aquafeed resources in Zambia

There is a dearth of available data on the quantity of aquafeed resources used in Zambia. However, based on the survey conducted within the country, coupled with data on agricultural products and by-products generated locally, we highlight the current and potential feed resources in Zambia (Table 40). Their nutritional composition is represented in Table 41.

Ingredient	Currently used for aquafeeds	Source
Maize bran	Yes	Local
Maize meal	Yes	Local
Cassava leaf	No	Local
Cassava peel meal	No	Local
Wheat meal	Yes	Local
Wheat bran	Yes	Local
Rice bran	Yes	Local
Groundnut cake	Yes	Local
Bidens pilosa (blackjack)	No	Local
Sesbania sesban	No	Local
Potato peel and leaf	No	Local
Millet	No	Local
Rice bran	Yes	Local
Brewers' dried grain	No	Local
Sorghum	No	local
Soybean meal	Yes	local
Sunflower seed meal	Yes	local
Cotton seed meal	Yes	local
Blood meal	Yes	Local
Fishmeal	Yes	Imported
Termite meal	No	Local
Feather meal	Yes	Local
Poultry meal	No	Local
Beef and pork meal	No	Local
Sugar cane pulp	No	Local

Table 40. Available ingredients (both plant and animal origin) for aquafeed production in Zambia.

10.4.1 Current feed ingredients in Zambia

10.4.1.1 Protein sources: Plant origin

Soybean meal

In Zambia, soybean meal is the most predominant plant protein ingredient used in aquafeed and is exclusively produced within the country (27,000 t in 2016) (FAOSTAT 2016). Soybeans are cultivated in all parts of Zambia, both by smallholder and large-scale farmers, with Eastern, Central and Northern provinces being the largest contributors (Lubungu et al. 2013). Giant soybean processing plants such as Cargill, Golden Commodity and Mount Meru are located in Lusaka. Soybean meal needs to be transported to other parts of the country. One important aspect of soybean cake/meal being used as a raw material in animal feed is that it may impact soy-based human foods, which are important for the poor as an alternative to animal protein (Steve Cole, personal communication, 2018).

Cotton seed meal

Cultivation of cotton seeds is mainly done in Southern, Eastern, Lusaka, Copperbelt, Western and Central provinces, with about 100,000 t produced in 2016. Zambia is a net exporter of cotton, especially to South Africa, Mauritius and East Asia, and it is widely grown by smallholder farmers, with about 300,000 farmers growing cotton for a combined USD 40 million annually (CDT 2014). Seed cotton produces 40% lint, 57% cotton seeds and 3% waste (UNCTAD 2016). Oil

Ingredient	Protein (%)	Lipids (%)	Carbohydrates (%)
Plant ingredients			
Beans	15	1	40
Beer waste	22	-	-
Cassava leaf	21	6	13
Cassava meal	1	-	37
Groundnut cake	53	-	-
Groundnut seed	26	49	16
Maize bran	8	1	65
Maize meal	8	4	77
Millet	11	4	73
Rice bran	13	21	50
Sorghum	11	4	75
Soybean meal	35	21	35
Sunflower cake	12	74	14
Sunflower seed	21	51	20
Animal protein sources			
Blood meal	81	1	-
Termites	55	3	35
Wild plants			
Amaranthus spp.	13	7	65
Bidens pilosa (blackjack)	25	4	56
Sesbania sesban	24	6	61

Source: Hänninen 2014.

Table 41. Nutritional composition of aquafeed ingredients in Zambia (values for dry matter, ash and crude fiber not available).

is extracted from the seeds and the remaining meal is available for use in aquafeed. Cotton seeds contain high levels of edible oil (18%–25%) and protein (50%) depending on seed quality and species (UNCTAD 2016). Poultry feed offers strong competition to the incorporation of cotton seed meal into aquafeed.

Sunflower meal

Sunflower is widely grown throughout Zambia, particularly in Eastern Province, which is responsible for 40% of sunflower production in the country (Lubungu et al. 2014). In 2016, 60,000 t were produced, mainly for commercial oil production. The oil extraction process is accompanied by sunflower meal, which is an important plant protein source in animal feed. Despite the paucity of data on the overall quantity of inland sunflower meal, the product is consistently used by Zambian aquafeed manufacturers. Sunflower meal is used also in livestock feed, which limits the amount available for fish feed. Giant oil extraction plants are located in Lusaka, but some small-scale extractors are also present in rural areas (Lubungu et al. 2014). Unfortunately, the cake from small-scale extractors is often of poorer quality.

Groundnut meal

Groundnut is another important oil cake crop produced in the country, mainly for human consumption. Approximately 153,000 t were generated in 2016 (FAOSTAT 2016). Groundnut is produced in every part of the country, though about half of the country's production comes from Eastern and Northern provinces (Ross and de Klerk 2012). Groundnut production starts in November or early December at the onset of the rainy season (Ross and de Klerk 2012). The seeds are mainly used in the production of groundnut butter and are less available for aquafeed. The seeds are also used to make cooking oil. Groundnut meal is left after the oil extraction and is then made available for fish feed. About 3000 t of groundnut meal are generated annually in the country (Indexmundi 2017). An important aspect to groundnuts (and also other crops) is the contamination of aflatoxin, which is significant in Zambia. It begins on the farm and exacerbates as groundnuts are stored (Steve Cole, personal communication, 2018). An important future research question is to find out the impact of aflatoxin on performance of fish fed feeds produced with Zambian-grown maize, soy beans, groundnuts, etc.

10.4.1.2 Protein sources: Animal origin

Blood meal

Currently, the livestock sector is among the fastest growing sectors in Zambia. As such, poultry and pork meats are widely consumed throughout the country. These are left with several useful by-products, including blood, which can be processed into blood meal and used as an ingredient in aquafeed. Unfortunately, the blood meal produced in the country is of poor quality, so feed manufacturers depend on imports from neighboring countries, particularly South Africa. There is no available information on the quantity of blood meal produced domestically, but considering the amount of poultry, pork and beef produced in the country, there is opportunity to better use by-products, such as blood and other "waste" products. Efforts should be directed at improving the quality of locally produced blood meal.

Feather meal

In 2016, there were 48,470 t of chicken meat produced in Zambia. Unfortunately, there is no data on the quantity of feather meal generated in the country, though both locally produced and imported feather meal are available. The local feather meal is mainly produced by poultry processors for their sister feed companies. For instance, Zambeef's feather meal is used by Novatek (author's field survey 2018). As a result, domestically produced feather meal is not freely available for purchase in the market, and most feed producers lacking access to the domestic produce rely on imports, mainly from South Africa and Namibia. Zambia's capacity to produce feather meal is currently underused, so other chicken processors should be encouraged to tap into this potential. The availability of feather meal for fish feed is mainly constrained by competition from poultry feed.

Poultry meal

Apart from feather meal, other inedible parts of chicken, such as offal, can be use in poultry meal. Currently, however, this is not done in Zambia, which makes it an untapped resource in the country. Poultry meal is mainly imported. Using a conversion factor that on average 16% of total broiler weight is offal, with the amount of chicken production stated above, approximately 7700 t of poultry meal could be produced.

Fishmeal

Zambia has no records on fishmeal production. All the fishmeal used in aquafeed production is entirely imported from foreign countries, especially South Africa, Namibia and Mauritania. This is, in part, leading to comparatively high costs in aquafeed production, so efforts should be geared toward complete or partial replacement with local plant protein feedstuff in Zambian fish feed.

10.4.1.3 Energy and fiber sources: Plant origin

Maize and maize bran

Maize is the most important staple food for Zambians, and it is an equally important energy concentrate in livestock feed. Total maize production in Zambia in 2016 was 2.8 million metric tons (FAOSTAT 2016), which is sufficient to meet both human and animal needs. Maize is mostly produced by small-scale farmers in regions I and II. Aside from using maize meal in aquafeed, maize bran is a by-product of maize that is also used in fish feed. Maize milling companies are mainly concentrated in Lusaka. Although there is a lack of information on the quantity generated annually, there is sufficient maize bran available to meet the demands of both the aquafeed and poultry feed sectors.

Wheat and wheat bran

Considering its quality, wheat is the second-most important grain produced in the country, with an estimated 160,000 t produced in 2016 (FAOSTAT 2016), mostly for human consumption. However, wheat bran, a by-product of wheat milling, is widely available and used in the production of fish feed, despite the unavailability of accurate data on the quantity generated annually in the country. It is noteworthy to mention that wheat production has declined in recent years because of El Nino during the 2015 season. Feed-food competition is another major impediment threatening the availability of this feedstuff for aquafeed production.

Cassava meal and leaf

Cassava is widely produced throughout Zambia, mainly by smallholder farmers. To some extent, cassava meal is used by some feed producers, but to the author's knowledge no company is currently using its leaves in aquafeed. The total production of cassava in Zambia stands at about 1 million metric tons annually (FAOSTAT 2016), of which small-scale farmers are responsible for the majority of the production. Cassava production and processing generate by-products—such as cassava leaves and peels, which contain appreciable protein and energy levels—that can serve as important feed ingredients in aquafeed. Cassava leaf meal production needs further exploration in the future.

Rice bran

Zambian rice production in 2016 was 27,000 t according to FAOSTAT. Rice bran is widely used in aquafeed, though the availability of rice bran for aquafeed is limited by its use in livestock feed. There is no data on the amount produced within the country, but rice milling produced 10% rice bran, so an estimated 2700 t of rice bran is generated in 2016.

10.4.1.4 Oil and fat

Fish oil, soybean oil, groundnut oil, sunflower oil and cotton seed oil are the available sources of lipids in Zambia.

10.4.2 Future feed ingredients in Zambia

10.4.2.1 Protein sources

Sorghum and brewery waste

Sorghum, which is directly consumed as food, is cultivated in all parts of the country, with about 14,000 t produced per year (FAOSTAT 2016). It is also used in beer production. Planting starts in the first week of December and sometimes extends to mid-January. Sorghum meal can be used as an energy source in aquafeed, but current inland production is mainly used for human consumption (for beer brewing), so it not available for aquafeed production, though the by-products of the brewing process are very useful for feed production. When dried, the waste contains 22% crude protein. SABMiller was the biggest beer company in the country, and it recently entered a merger with another global beer giant, AB InBeV. This is expected to boost beer production in the country, which will increase the quantity of brewery waste available for animal feed. Therefore, the possibility of using brewery waste in aquafeed requires further research.

Beef and pork meal

In 2016, there were 202,000 t of beef and 43,000 t of pork produced in Zambia (FAOSTAT 2016).

Offal and other inedible parts of the animals can be rendered and used as aquafeed ingredients. Zambia is largely a Christian country, so including pork meal in aquafeed should be widely accepted. These untapped resources should be looked into in the future.

10.4.2.2 Other nutrients

Millet

Total Zambian wheat production currently stands at 30,000 t per year (FAOSTAT 2016). Millet is cultivated extensively in the three agro-ecological zones. Common varieties are *kaufela*, *lubesi*, *sepo*, *tuso* and *kuomoka*. Planting begins at the onset of rainfall around November/December every year. The entire production is meant for human purposes, so millet is unavailable for use in aquafeed.

Sugarcane by-products

Sugarcane is predominantly cultivated under irrigation in Northern and Southern provinces of the country, especially in Mazabuka, Kafue and Kalungwishi (USDA 2017). The Zambian sugar industry has grown over the past few decades, with Zambia Sugar Plc. responsible for more than 90% of the total sugar production (USDA 2017). Kafue Sugar and Kalungwishi Kasama Sugar are two other sugar milling companies. In 2016, 4.2 million metric tons of sugarcane were produced in the country (FAOSTAT 2016) of which 411,000 t of sugar were manufactured (USDA 2017). Sugar production generates by-products such as bargasse, molasses, pith and mud, which can all be considered as potential aquafeed ingredients, though they are high in fiber and are likely to be less digestible in fish.

Potatoes peel and leaf

There are three potato-growing seasons in Zambia: the rainfed crop is grown around November, the first irrigation crop is planted in January/February and the second irrigation crop is grown around July. About 230,000 t were generated in 2016 (FAOSTAT 2016). Potato by-products, such as peels, leaves and other parts, can be considered as ingredients for fish feed.

Tomato waste

Tomato is another important food crop produced in Zambia, predominantly in Central, Copperbelt, Eastern and Northern provinces, with an annual production of 26,000 t (FAOSTAT 2016), and it is sold either fresh (open markets or supermarket chains) or to tomato canning companies. Approximately 15% of Zambian tomatoes are purchased by processing companies, particularly Rivonia, Freshpikt and Sylva Food (Neven et al. 2008). Pomace, a by-product of tomato processing, could be considered as a future fish feed ingredient.

Coffee by-products

Zambian coffee production in 2016 was 7000 t (FAOSTAT 2016). The production areas are Central, Lusaka and Northern provinces (ZDA 2011). Coffee processing generates by-products, such as hulls and pulps, which could be used in fish feed.

10.4.3 Priority aquafeed ingredients for further research in Zambia

Table 42 shows the list of locally produced feed ingredients that could be considered for further research in Zambia.

10.4.4 Conclusions for Zambia

Fishmeal coupled with blood meal, poultry meal and feather meal are the most common animal protein sources for aquafeed. These animal protein ingredients are complemented by plant protein feedstuffs, such as soybean meal, groundnut cake, cotton seed meal and sunflower seed meal, which are readily available within the country. The energy in fish feed is mainly supplied by plant sources such as maize meal, maize bran, wheat meal, wheat bran and rice bran. Cassava peel is a readily available by-product from cassava processing and can be incorporated into aquafeeds. Agro-industrial by-products, such as beef and pork meal, sugar cane pulp, potato peels and leaves, tomato waste and coffee by-products, can be considered as aquafeed ingredients, but their use is limited by the quantities available in the country. Novel feed ingredients, such as algae, insect meal, microbial biomass, etc., could be at the forefront of future research in Zambia.

Ingredient	Research action(s) needed
Protein sources	
Fishmeal	• The majority is sourced from neighboring countries, such as South Africa and Namibia. • Replace fishmeal in aquafeed with alternative protein sources.
Sunflower seed meal	• Further information needed on the volume available within the country.
Soybean meal	• Zambia is self-sufficient in soybean seed production. • Alternative protein sources are needed to augment the use of locally produced soybean meal.
Cotton seed meal	• Further information needed on the volume of cotton seeds produced in Zambia.
Groundnut cake	• Further information needed on the available volume within the country. • Improve processing methods to decrease the contents of mycotoxin present in locally produced groundnut cake.
Cassava leaf protein	• Further information needed on the volume available within the country. • Organize logistics around the collection of cassava leaves for production of cassava leaf protein.
Brewers' dried grain	• Further information needed on the volume available within the country. • Improve processing methods to increase the level of proteins present in brewers' dried grain.
Feather meal	• Improve collection and processing methods to increase availability of feather meal for aquafeeds.
Blood meal	• Improve collection and processing methods to increase availability of blood meal for aquafeeds.
Beef and pork meal	• Further information needed on the availability within the country.
Poultry meal	• Organize logistics around collection of poultry offal for use in poultry meal production. • Set up rendering facility for commercial production of poultry meal.
Energy sources	
Maize meal	• Replace with quality alternatives that have less or little competition from humans and livestock.
Maize bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Cassava peel	• Increase the inclusion level through appropriate research without compromising fish growth. • Investigate the use of cassava peels in fish diets. • Improve processing methods to decrease the fiber content of cassava peels.
Sorghum and sorghum bran	• Further information needed on the quantities available for aquafeed production.
Wheat meal	• Replace with quality alternatives that have less or little competition from humans and livestock.
Wheat bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Rice bran	• Increase the inclusion level through appropriate research without compromising fish growth.
Sugar cane pulp	• Further information needed on the quantities available within the country.
Potato leaf and peel	• Further information needed on the quantities available within the country.

Table 42. Priority ingredients to be considered for aquafeed, with proposed further research to improve their nutritional quality.

11. Novel feed resources

Novel feed ingredients are expected to reduce the pressure imposed on the use of fishmeal and soybean meal in animal feed. The potential of these novel ingredients in the selected countries is briefly examined below.

11.1 Insect meal and worm meal

Entomophagy has been practiced for a long time. However, the commercial production of insects with the aim of using them as animal feed caught worldwide attention not too long ago. In 2017, the European Union accredited insect meal to be used as a fish feed ingredient. The most important insect species are housefly maggot, black soldier fly and mealworm, of which the meals are used as feed ingredients. Crickets, which are increasingly being farmed but at a lower-scale, are considered to have better nutritional quality for fish than fly larvae. Technologies for large-scale production of these insect meals do exist, but their current production costs limit their use in animal feed. In addition, the total production is currently too low to have commercial feed producers to structurally source insect meal as an ingredient in their products. Insect meal is also more expensive than fishmeal and soybean meal. The amino acid composition of insect meal is very suitable for fish feed, but constituents like chitin retard their digestibility in fish because they lack endogenous chitinase to effectively use chitin. However, different extraction methods exist to separate chitin from the final insect meal. Additionally, the fatty acid composition of insect meal is often less suitable for fish, especially when insect larvae are grown on waste products such as manure. Quality grain products are used as cultured substrates to improve the fatty acid composition of insect meals. Alternatively, insect meals can be defatted to remove the less quality fatty acids and increase their nutritional quality.

The use of worms, particularly in backyard fish farming, is also prominent in some of the target countries. Notable worms of interest are earthworms and mopane worms (mainly found in Zambia). Mopane worm is a common source of protein for humans in Zambia. The crude protein and lipid contents of the major insect meal and worms are summarized in Table 43. The countries considered in this report have a perfect environment to support the natural productivity of these insects, so efforts should be geared toward massive production within the different countries.

11.2 Single cell protein

Single cell proteins (SCPs) have been recognized as a valuable protein biomass to be used in animal feed. SCPs are derivatives of unicellular or multicellular organisms, be it bacterial cells or yeast, that can be consumed by both humans and animals. SCPs have considerable amounts of protein (50%–85% crude protein), amino acids, vitamins and minerals that are favorable for fish performance. They can be cultured using agricultural or industrial wastes as substrates,

Insects/worms	Crude protein (%)	Lipids (%)	References
Insect meal			
Housefly maggot	40–60	9–26	Makkar et al. (2014)
Housefly pupae	65–73	14–16	Makkar et al. (2014)
Black soldier larvae	40–44	15–25	Makkar et al. (2014)
Mealworm	47–60	31–43	Makkar et al. (2014)
Locust	50–65	5–20	Makkar et al. (2014)
Silkworm pupae	52–72	1–9	Makkar et al. (2014)
Termite	46	30	Sogbesan and Ugwumba (2008)
Worms			
Earthworm	63	5.9	Sogbesan and Ugwumba (2008)
Mopane worm	54	16	Kwiri et al. (2015)

Table 43. Insects of economic value as feed ingredients.

such as carbon dioxide, hydrogen, methane, alcohol, molasses and wood chips. The kind of substrates used often influence the nutritional composition of the final cell mass. Companies responsible for massive production of SCPs mostly reside in developed countries, so it may be worthwhile to initiate commercial production of SCPs in the selected developing countries. Three important issues of concern before using SCPs in aquafeed are (1) the presence of toxins or carcinogenic substances, (2) the low nutritional efficiency caused by the presence of structural barriers, such as the cell wall, and (3) the level of nucleic acids present.

11.3 Algae

Algae (both micro and macro), which constitutes the primary trophic level in a pond ecosystem, is another important protein of the future. Algae made up of is photosynthetic eukaryotic plants that harbor appreciable protein and fat contents usable for fish growth. Mass production under laboratory conditions has been in practice for years now, and an array of nutritional and toxicological studies have demonstrated the suitability of algae biomass as a valuable feed ingredient (Becker 2007). Several species of microalgae are available for commercial cultivation (the nutritional values of few of them are listed in Table 44). The cellulosic cell wall encapsulates nutrients embedded within the algae cells and may reduce their digestibility for fish because they lack the endogenous cellulase needed to degrade those cell walls. Enzymatic, chemical, physical and mechanical disruption methods are promising to effectively use algae in fish diets. *Ulva lactuca* and *Pterocladia capillacae*, two of the dominant macroalgae, along the Egyptian Mediterranean coasts, have been demonstrated as suitable protein supplements for mullet (Wassef 2005).

11.4 Duckweed

Duckweed is a valuable aquatic plant that can be industrialized and used in farmed fish feeds. There is evidence of duckweed cultivation in some of the selected countries (e.g. in Nigeria, where tilapia farmers cultivate azolla in abandoned ponds and feed it directly to their fish) though not on a large scale. Azolla is also cultivated in Egypt as feed for ducks. There are other duckweed species used to remove nutrients from waste water before being discharged into water bodies. Duckweed is rich in both micro and macronutrients and can help to reduce the pressure imposed on grains and legumes by aquafeed. Protein constituents range from 20% to 45%, lipids 2%–15% and crude fiber 3.8%–25% (Mwale and Gwaze 2013). The fiber content of duckweed limits its use in fish feed. In all the focal countries, commercial cultivation of duckweed species is nonexistent, making this an area for future research.

Alga	Protein	Carbohydrates	Lipids
Anabaena cylindrica[1]	43–56	25–30	4–7
Aphanizomenon flos-aquae[1]	62	23	3
Chlorella pyrenoidosa[1]	57	26	2
Chlorella vulgaris[1]	51–58	12–17	14-22
Dunaliella salina[1]	57	32	6
Euglena gracilis[1]	39–61	14–18	14–20
Porphyridium cruentum[1]	28–39	40–57	9–14
Scenedesmus obliquus[1]	50–56	10–17	12–14
Spirogyra spp. [1]	6–20	33–64	1121
Arthospira maxima[1]	60–71	13–16	6-7
Spirulina platensis[1]	46–63	8–14	4-9
Synechococcus sp. [1]	63	15	11
Chlamydomonas rheinhardii[1]	48	17	21
Ulva lactuca[2]	18	40	2.5
Pterocladia capillacea[2]	23	28.2	2

Sources: [1]Becker 2007 and [2]Wassef 2005.

Table 44. Percentage nutritional composition of algae (% of dry matter).

12. Sociocultural limitations of using the ingredients

Various externalities influence the use of ingredients in fish feed, one of which is the sociocultural limitations. These encompass the different aspects of social interaction, such as social amenities, customs, beliefs and religious inclination, that directly or indirectly influence the use of certain ingredients in some of these focal countries. It is imperative to have a proper understanding of prevailing constraints to develop more realistic solutions in each of the selected countries. As a result, sociocultural limitations will be addressed from the angle of social infrastructure, religious inclination and consumer perception to some ingredients.

12.1 Social infrastructure

In the different target countries, infrastructure is often deficient in rural areas. Crop farmers (the major producers of plant-based ingredients) often face difficulties in transporting products to their consumers (feed manufacturers and ingredient suppliers). Fish farmers also experience similar dilemmas. The lack of proper roads often poses a serious threat to the free flow of inputs in and out of the farms, and poor road network system leads to underexploitation of feed ingredients prevalent in a country. As such, feed ingredient users such as fish farmers, large-scale suppliers and feed manufacturers have shifted their attention to places where ingredients can be easily sourced. Often, ingredients are sourced far away from their source of usage. For instance, a large proportion of fish feed ingredients used in the southern part of Nigeria, where fish are produced, are sourced from the northern part of the country. This takes at least 3 days to transport, and conditions often affect ingredient quality.

Two other social constraints are inadequate storage and processing facilities. The majority of plant-based feedstuffs are seasonally produced. Plant ingredients are usually stored for off-season usage, but a lack of storage facilities causes fluctuations in ingredient availability, so this must be taken into consideration in developing sustainable fish feed formulation in each country. Sun drying is the major source of drying plant materials, particularly maize.

Although sun drying is cheap, it faces a number of challenges, such as uncontrollability of drying parameters, labor intensity, liability to dirt and microbial contamination, restrictions on periods of sunlight, inability to control uniform dry matter in the final products, and sensitivity to other weather variables, such as rain and wind. Drying is discontinued in the presence of rain and heavy winds. Alternative drying methods are driven by electricity. This is quite expensive and unaffordable for peasant crop farmers, so sustainable alternative energy sources should be given utmost attention in conceptualizing improved processing methods for ingredients.

12.2 Religious inclination

Religious injunction permits or prohibits adherents from consuming certain products. This extends to the choice of ingredients in feeding their animals, including fish. Muslims are known for prohibiting their consumption pork or any of its products. In Muslim dominated countries such as Egypt, Bangladesh, Malaysia and northern parts of Nigeria, there is a restriction on the use of animal products (blood meal, poultry meal, pork meal, bone and meat meal, etc.) from animals emanating from nonhalal slaughtering. Such restrictions prevent the use of certain ingredients in fish feed, and as a consequence should be of considerable concern during fish feed formulation.

12.3 Consumer perception

Insects are heavily considered as novel feed ingredients, so it is necessary to understand consumer perception toward insect feeding for fish. Although entomophagy has been going on for years in many parts of Africa and Asia, in some quarters many still consider this abhorrent because of their beliefs and tradition. Before introducing insects and other novel ingredients into these countries, a structural framework covering production technologies, upscaling, safety (fish and human), legislation and consumer acceptability of the final products should be considered.

12.4 Gender inclusiveness

Women have been involved in crop production for decades, mainly in harvesting and postharvest processing. In all focal countries, there is no pronounced or written law that restricts women participating in feed ingredient ventures. However, given the dominance of males in that business, women are restricted from participating or acting as large-scale suppliers for any reputable feed industry, though women do participate greatly on a small- or medium-scale basis, without any restrictions, whether cultural, social or religious. Until now, youth participation in agriculture has always been low because agriculture is perceived as drudgery and stressful. However, this perception is changing, and more youths are venturing into agriculture, including the feed ingredients business. The major limitation to youth participation is more economic than sociocultural.

Large-scale cage culture on Lake Kariba, Kariba Harvest.

13. Environmental impact

In developing sustainable fish feeds, the whole process of feed production should be done in a socially and environmentally responsible manner, and the sustainability framework of people, planet and profit should be strictly adhered to. The production of feed ingredients, both of plant and animal origin, has both beneficial and detrimental impacts on the environment, and this can be measured through life-cycle assessment tools. In this report, a comprehensive environmental assessment of the various aforementioned ingredients was not conducted. However, nonexhaustive environmental impact covering the different processes involved in production, transportation, storage and use of fish feed ingredients is provided below.

13.1 Nitrogen fixation

Nitrogen is an integral nutrient needed for plant growth and survival. It is vital for many plant biological processes, including chlorophyll formation, amino acids synthesis, energy transfer and reproduction. Replenishing the nitrogen in the soil for plant uptake is mostly done through inorganic or organic fertilization, though some plants (e.g. soybean) have the capability to fix nitrogen into the soil with the aid of nitrogen-fixing microorganisms at their roots. Nitrogen fixers help to reduce soil fertilization and are used in reclaiming nitrogen-deficient soil through farming practices such as crop rotation and mixed cropping.

13.2 Environmental issues

Agricultural by-products such as cassava peel, blood and feathers are indiscriminately disposed and serve as an environmental menace, causing offensive odors and microbes that are very harmful to humans. The "waste" is sometimes channeled into water bodies, such as lakes, rivers and streams, where they are often detrimental to the growth and survival of aquatic organisms. Converting agricultural by-products into valuable feed resources helps create wealth from waste, as low-value by-products are converted into valuable fish biomass.

13.3 Soil enrichment

Leftover harvested cereals and oil seeds are ploughed back into the soil as organic material. Decomposition of these residues increases organic matter in the soil and contributes to the nutrient pool in the soil. Crop residues such as maize stalk, cassava leaves, soybean and groundnut shoot, feathers and cassava peel can also be used as compost, which when added to the soil helps to replenish and improve its nutrients.

13.4 Water eutrophication

Inorganic fertilizers are usually added to the soil to supply the necessary nutrients needed to grow and develop crops. Commonly used fertilizers are urea, NPK, superphosphates and phosphate rocks, depending on the particular nutrient lacking in the soil. Excessive fertilizer application creates a hypertonic soil solution that is often detrimental to soil microorganisms and other soil biota. Also, runoff water from crop fields contains high concentrations of nutrients, mainly nitrogen and phosphorus, that are disposed of in nearby water bodies. This causes eutrophication, which can reduce the photosynthetic activities of plants in the water and deplete oxygen levels in the water, which lead to the death of aquatic plants and animals.

13.5 Emissions during transportation

Transportation of ingredients to end users has environmental costs that contribute adversely to climate change, because it is mainly done with heavy trucks that emit greenhouse gases. Additional carbon dioxide released through anthropogenic sources such as fossil fuel combustion and deforestation increases the greenhouse effect, causing global warming. Carbon monoxide from vehicle emissions may also lead to carbon monoxide poisoning. Carbon monoxides bind with hemoglobin, which carry oxygen through the blood, to produce carboxyhemoglobin, which inhibits the transport and use of oxygen in the body.

13.6 Respiratory problems from dustiness

Dust is a common air pollutant generated during processing of maize, wheat, cassava peel, etc., into meal. Dust is detrimental to human health, and inhaling it for a long period can lead to a number of respiratory problems, such as sneezing, coughing and asthmatic attacks. Continuous breathing of a large concentration of dust over many years can lead to chronic bronchitis, heart and lung disorders.

14. Feed-food-fuel competition

The demand for fish feed ingredients is expected to rise in step with future aquaculture growth. Over the years, there has been competition to use feed resources for food, feed and fuel. Similar resources are used as food, for feeding animals and as biofuel substrate. However, in the various focal countries there is no information on the consumption data for each category (food, feed and fuel). Since the overall objective is ensuring food security, it is necessary to use these resources for food, feed and fuel production in the most responsible and efficient manner possible. Disentangling resource demand remains imperative for the three components in the focal countries through appropriate research. More importantly, it is important to understand the demand for feed ingredients for the different animal enterprises practiced in each country. This will give a comprehensive insight into annual country requirements for feedstuff.

15. Antinutritional factors in each ingredient (if present)

Antinutritional factors (ANFs) are substances that interfere with digestibility and efficient use of feed nutrients. ANFs also reduce the inclusion rate of ingredients because fish can only handle them in limited amounts, without adverse effects, because of their digestive tract. The effect of ANFs can be ameliorated through a series of pre-treatments and dietary strategies. Previous studies have given comprehensive detail of the numerous ANFs found in plant resources (Francis et al. 2001; Gatlin et al. 2007; Kumar et al. 2012). Common ANFs found in major aquafeed ingredients are represented in Table 45.

ANFs	Ingredients	Remediation strategies
Interaction with protein		
Protease inhibitors	Soybean, rapeseed meal, jactropha kernel meal, lupin seed meal, sunflower oil cake, pea seed meal, sesame meal	Heat, autoclaving
Hemagglutinins (lectins)	Soybean meal, jatropha kernel meal, pea seed meal	Heat, autoclaving
Saponins	Peas, alfafa, lupin seed meal, sunflower oil cake, alfafa leaf meal	Heat, autoclaving
Polyphenols (Tannins)	Tannins, sorghum, jatropha kernel meal, pea seed meal, mustard oil cake	
Interaction with mineral availability		
Phytic acid	Soybean, jatropha kernel meal, pea seed meal, cotton seed meal, sesame meal, leaf proteins	Phytase supplementation
Oxalic acids	Leaf proteins	Heat treatment
Glucosinolates	Rapeseed, mustard oil cake	Genetic improvement
Gossypol	Cottonseed meal	Genetic improvement
Interaction with vitamin availability		
Vitamin A (lipoxygenase)	Soybean	Heat treatment
Vitamin D	Soybean	Autoclaving
Vitamin E (oxidase)	Kidney beans	Autoclaving, addition of vitamin E
Antinicotinic acid	(niacinogen) maize	
Antipyridoxine	Linseed meal	Water extraction, heating
Antivitamin B12	Raw soybean	Heat treatment
Cyanogens	Cassava, sorghum, pea seed meal	Heat treatment
Mimosine	Leucaena leaf meal	
Arginase inhibitors	Sunflower oil cake	
Cyclopropenoic acid	Cottonseed meal	
Antivitamins	Alfafa leaf meal, cottonseed meal, pea seed meal, soybean meal	
Others		
Alkaloids	Lupin seed meal	
Phytoestrogens	Soybean meal, lupin seed meal	
Allergens	Soybean meal	
Groundnut seeds	Mycotoxin (aflatoxin)	Optimum storage condition
Feather meal	Keratin	Hydrolyzation
Poultry and blood meal	Contamination	Heat treatments
Insect meal	Chitin	Chitin extraction/removal

Sources: Francis et al. 2001 and Kumar et al. 2012.

Table 45. Common antinutritional factors in major aquafeed ingredients.

16. Priority ingredients for future research under the FISH CRP in the focal countries

To achieve maximum impact in the focal countries, FISH CRP research should focus on upgrading the use of 10–15 common ingredients in fish feed. These ingredients are listed in Table 46.

The following research activities are proposed for every ingredient:

- Outline the nutritional composition of each ingredient.
- Conduct digestibility trials with the most relevant fish species in each country.
- Detail the batch-to-batch variability within each country and between the different focal countries.
- Detail the value chain of distribution, consumption and use of each ingredient, which will help to understand the feed-food-fuel competition associated with a particular ingredient.
- Conduct a gender study on accessibility of these ingredients for women and youths in the different countries.

Ingredient	Focal countries
Cassava peel and leaf	Bangladesh, Malaysia, Nigeria and Zambia
Beet pulp	Bangladesh, Egypt, Nigeria and Zambia
Sugar cane pulp	Bangladesh, Egypt, Nigeria and Zambia
Maize bran	Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia
Groundnut cake	Bangladesh, Malaysia, Egypt, Nigeria, Zambia
Feather meal	Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia
Poultry meal	Bangladesh, Egypt, Nigeria, Zambia
Blood meal	Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia
Shrimp meal	Bangladesh, Myanmar, Egypt and Nigeria
Squid meal	Myanmar and Malaysia
Brewers' dried grain	Malaysia, Nigeria and Zambia
Rice bran	Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia
Rice polish	Bangladesh and Egypt

Table 46. Priority ingredients for the FISH CRP in the focal countries.

17. Conclusions

This report provides a comprehensive overview of the commercially available aquafeed ingredients in the focal countries of the FISH CRP: Bangladesh, Myanmar, Malaysia, Egypt, Nigeria and Zambia. For all six countries, energy ingredients such as maize, cassava and wheat by-products are abundantly available. However, protein sources are less available. In this regard, animal by-products such as blood meal, poultry meal and feather meal are valuable protein sources. Most of the focal countries produce large quantities of poultry and other livestock, but conversion of waste emanating from these sectors into ingredients is currently underexploited. In addition, plant protein sources such as soybean meal (produced locally in some instances), groundnut meal, sesame meal and sunflower meal offer great potential as protein sources. Also, agro-industrial co-products, such as brewers' waste, sugar beet pulp, sugar cane pulp and tomato waste, can be considered as aquafeed ingredients. Novel feed ingredients such as insect meal, worm meal, SCPs and algae offer promising perspectives as future ingredients but require further research.

Data on crop production per country is widely available, but data on the production volume of ingredients is limited. Likewise, information on the nutritional composition of the available ingredients in a particular country is either unavailable or disjointed. From the available data, we observe a high variability in the nutritional composition of the different ingredients within a particular country. In the future, it might be important to monitor and understand the variability of the ingredient quality between seasons, geographical origin or even from batch to batch. This may be used to develop proper research strategies, which in turn can be used to educate different stakeholders (crop farmers, ingredient processors, etc.) on how to improve the cultivation, harvesting and processing of crops, and to stabilize and upgrade them to a minimum level of quality. Value chain analyses of aquafeed raw materials and their nutritional contents in each country might provide useful information and so this should be made publicly accessible to end users (farmers, feed manufacturers, etc.).

Since the overall aim is to provide sustainable fish feed to meet the increasing growth of aquaculture in all the target countries, sourcing ingredients should be done in a sustainable and environmentally responsible manner. Additionally, sociocultural constraints should be considered when feeds are formulated. For instance, pork meal is unacceptable as an aquafeed ingredient in Muslim-dominated communities. In addition, some ingredients harbor antinutritional components that impair nutrient availability in fish, so strategies to ameliorate these components should be devised in subsequent research. The majority of the aforementioned feedstuff is also used for food and fuel as well as feed for livestock.

In conclusion, for an ingredient to be considered viable for aquafeed, it must be commercially available, nutritionally adequate, easy to handle, offer little or no competition for human food and fuel, have a limited negative footprint on the environment and meet the sociocultural considerations of the people.

18. Recommendations for future research

- Feed assessment tools to comprehensively understand available fish feed resources in a selected location are currently lacking, so future efforts should be geared toward developing such tools, taking a clue from the Feed Assessment Tools developed by the ILRI for livestock.[10]

- Data on the nutritional composition of available feed ingredients in the target countries is scarce, and where it exists, amino acid profiles, fatty acids and mineral composition are often missing. Therefore, future research should be targeted at holistic nutritional analyses of the available feed ingredients.

- The available data on local feed resources in these countries is often disjointed or segregated. Therefore, a consolidated website should be developed to host data on production, nutritional composition, antinutrition factors, environmental impact and other information of all available ingredients in WorldFish focal countries. This should be made publicly accessible to end users, such as fish farmers and feed manufacturers.

- Cross-CRP collaboration should be established with other CGIAR institutes, especially the ILRI, IITA and the International Center for Tropical Agriculture. In Nigeria, the ILRI is currently developing an innovative approach to use cassava peel meal in animal diets. Such research can also be adopted under FISH in collaboration with the appropriate institutions.

- Waste from livestock (poultry offal, feathers, blood) remain unused in some of these countries, so innovative processing methods to convert them into feed ingredients should be given attention in the future.

- Dietary optimization of local feed resources through different biological studies should be of concern in the next phase of research.

- There seem to be opportunities for research to increase the production of novel feed ingredients in all the focal countries.

Notes

[1] https://go.alltech.com/hubfs/GFS2018%20Brochure.pdf?hsCtaTracking=a5b7e25c-9ffc-49fa-9155-172c7eb289f7%7C0bb51f65-30c4-40e0-b48b-76a14eacf4d3

[2] https://www.cia.gov/library/publications/the-world-factbook/fields/2116.html

[3] http://enacademic.com/pictures/enwiki/66/Burma_en.png

[4] https://enaca.org/?id=896&title=status-of-aquaculture-feed-and-feed-ingredient-production-in-myanmar

[5] https://www.cia.gov/library/publications/the-world-factbook/fields/2116.html

[6] http://www.malaysiatrack.com/2014/07/malaysia-nature.html

[7] https://enaca.org/?id=894&title=status-of-aquaculture-feed-and-feed-ingredient-production-in-malaysia

[8] openi.nlm.nih.gov/detailedresult.php?img=PMC2572038_1471-2415-8-17-1&req=4.

[9] https://thezambianagropreneur.files.wordpress.com/2016/04/map-of-zambia-agro-ecological-regions.jpg

[10] https://www.ilri.org/feast

References

Abdel Hadi A. 2004. Country report on Egyptian agriculture. *In* Badraoui M, Bouabid R and Aït Houssa A, eds. Proceedings of the IPI workshop on Potassium and Fertigation Development in West Asia and North Africa Region. Horgen, Switzerland: IPI. 58–73.

Afreen N and Haque M. 2014. Cost benefit analysis of cassava production in Sherpur district of Bangladesh. *Journal of the Bangladesh Agricultural University* 12(1):119–26.

Agbebi O, Ilesanmi A, Alegbeleye W, Odulate D, Obasa S and Olaoye O. 2013. Growth and haematological effects of replacing maize with feed wastes on the juvenile clarias gariepinus (Burchell, 1822). *Journal of Fisheries and Aquatic Science* 8(4):535.

Ahammad M, Swapon M, Yeasmin T, Rahman M and Ali M. 2003. Replacement of sesame oil cake by duckweed (Lemna minor) in broiler diet. *Pakistan Journal of Biology Science* 6(16):1450–53.

Ahmed M, Abdullah N, Ahmed KU and Bhuyan M. 2013. Yield and nutritional composition of oyster mushroom strains newly introduced in Bangladesh. *Pesquisa Agropecuária Brasileira* 48(2):197–202.

Akande TO, Akinwumi AO and Abegunde TO. 2015. Cashew reject meal in diets of laying chickens: Nutritional and economic suitability. *Journal of Animal Science and Technology* 57(1):17.

Aktar M, Rashid M, Azam M, Howlider M and Hoque M. 2012. Shrimp waste and marine waste as substitutes of fish meal in broiler diet. *Bangladesh Journal of Animal Science* 40(1–2):18–22.

Al-kirshi R, Alimon AR, Zulkifli I, Sazili A, Wan Zahari M and Ivan M. 2010. Utilization of mulberry leaf meal (Morus alba) as protein supplement in diets for laying hens. *Italian Journal of Animal Science* 9(3):e51.

Al-Qazzaz MFA, Ismail D, Akit H and Idris LH. 2016. Effect of using insect larvae meal as a complete protein source on quality and productivity characteristics of laying hens. *Revista Brasileira de Zootecnia* 45(9):518–23.

Al Mahmud N, Hasan M, Hossain MB and Minar MH. 2012. Proximate composition of fish feed ingredients available in Lakshmipur region, Bangladesh. *American-Eurasian Journal of Agricultural & Environmental Science* 12(5):556–60.

Ali M and Leeson S. 1995. The nutritive value of some indigenous Asian poultry feed ingredients. *Animal Feed Science and Technology* 55(3–4):227–37.

Alimon A. 2004. The nutritive value of palm kernel cake for animal feed. *Palm Oil Development* 40(1):12–14.

Alimon A. 2009. Alternative raw materials for animal feed. WARTAZOA. *Indonesian Bulletin of Animal and Veterinary Sciences* 19(3):117–24.

Anetekhai M, Akin-Oriola G, Aderinola O and Akintola S. 2004. Steps ahead for aquaculture development in sub-Saharan Africa: The case of Nigeria. *Aquaculture* 239(1–4):237–48.

Asyifah M, Abd-Aziz S, Phang L and Azlian M. 2012. Brown rice as a potential feedstuff for poultry. *Journal of Applied Poultry Research* 21(1):103–10.

Ayinla OA. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Nigeria. FAO Fisheries Technical Paper, Rome: FAO. 497:453.

Azilah AJ, Abdullah A, Alimon A and Abd-Aziz S. 2013. Effects of feeding fermented sago pith meal on the growth performance of broiler chickens. World's Poultry Science Association (Malaysian Branch) and World Veterinary Poultry Association (Malaysian Branch) Scientific Conference, University Putra, Malaysia. 30 November–1 December 2013. 34–35.

Bakar S, Yeong SW and Seet CP. 1973. Direct substitution of maize with broken rice in the broiler diet. *Malaysia Agricultural Research and Development Institute (MARDI) Resource Bulletin* 1,2:37–40.

Baluyut EA and Balnyme E. 1995. *Aquaculture Systems and Practices: A Selected Review*. New Delhi: Daya Books.

Barman BK and Karim M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Bangladesh. FAO Fisheries Technical Paper. Rome: FAO. 497:113.

Basak B, Pramanik MAH, Rahman MS, Tarafdar SU and Roy BC. 2002. Azolla (Azolla pinnata) as a feed ingredient in broiler ration. *Internal Journal of Poultry Science* 1(1):29–34.

[BBS] Bangladesh Bureau of Statistics. 2004. Yearbook of agricultural statistics. Bangladesh Bureau of Statistics, 23rd edition. Dhaka, Bangladesh: Ministry of Planning.

[BBS] Bangladesh Bureau of Statistics. 2017. Yearbook of agricultural statistics. Bangladesh Bureau of Statistics, 28th edition. Dhaka, Bangladesh: Ministry of Planning.

Becker E. 2007. Micro-algae as a source of protein. *Biotechnology advances* 25(2):207–10.

[BFFEA] Bangladesh Frozen Food Exporters Association. Dhaka: BFFEA. Accessed 10 November 2017. www.bffea.net/export.php

Bhuiyan MRR, Bhuyan MS, Anika TS, Sikder MNA and Zamal H. 2016. Determination of proximate composition of fish feed ingredients locally available in Narsingdi region, Bangladesh. *International Journal of Fisheries and Aquatic Studies* 4(3):695–99.

[BIDA] Bangladesh Investment Development Authority. Dhaka: BIDA. Accessed 15 November 2017 www.boi.gov.bd

Chowdhury S. 2001. Effect of graded levels of cottonseed cake supplementation on intake, nutrient digestibility, microbial N yield of growing native bulls fed rice straw. *Asian Australian Journal of Animal Sciences* 14(3):326–32.

De Silva SS and Hasan MR. 2007. Feeds and fertilizers: The key to long-term sustainability of Asian aquaculture. *In* Hasan MR, Hecht T, De Silva SS and Tacon AGJ, eds. Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fisheries Technical Paper No. 497. Rome: FAO. 19–47.

Devendra C. 1986. Leucaena forage supplementation of ruminant diets in the ASEAN region. Paper presented at the international Workshop on Rice Straw and Related Feeds in Ruminant Rations, Kandy, Sri-Lanka, 24–28 March 1986. 1–25.

Diarra S and Usman B. 2008. Growth performance and some blood variables of broiler chickens fed raw or boiled mango kernel meal. *International Journal of Poultry Science* 7(4):315–18.

[DOF] Department of Fisheries. 2015. National fish week, compendium (in Bengali). Dhaka, Bangladesh: Department of Fisheries, Ministry of Fisheries and Livestock.

[DOF] Department of Fisheries. 2016. National fish week, compendium (in Bengali). Dhaka, Bangladesh: Department of Fisheries, Ministry of Fisheries and Livestock.

Donkoh A, Atuahene C, Wilson B and Adomako D. 1991. Chemical composition of cocoa pod husk and its effect on growth and food efficiency in broiler chicks. *Animal Feed Science and Technology* 35(1–2):161–69.

Eka H, Tajul Aris Y and Wan Nadiah W. 2010. Potential use of Malaysian rubber (Hevea brasiliensis) seed as food, feed and biofuel. *International Food Research Journal* 17:527–34.

El-Deek A, Al-Harthi M and Yakout H. 2008. Use of enzymes to supplement diets containing date waste meal for Lohmann White layers. *International Journal of Poultry Science* 7(4):397–407.

El-Lattief EAA. 2015. Cultivation of sesame in Egypt. *International Journal of Research in Engineering and Applied Sciences* 5(10):136–39.

El-Sayed A-F M. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Egypt. *In* Hasan MR, Hecht T, De Silva SS and Tacon AGJ, eds. Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fisheries Technical Paper No. 497. Rome: FAO. 401–22.

El-Sayed A-F M, Dickson MW and El-Naggar GO. 2015. Value chain analysis of the aquaculture feed sector in Egypt. *Aquaculture* 437:92–101.

El-Sheikh S, Al-Shokiry N, Salama A and Khidr R. 2013. Utilization of Azzawi date meal in local laying hen diets. *Egyptian Poultry Science Journal* 33(6):1115–27.

El Nagar A and Ibrahim A. 2007. Case study of the Egyptian poultry sector. Proceedings of the International Poultry Conference for the 21st Century, Bangkok, Thailand, 5–7 November 2007. 31.

Eyo A. 2003. Fundamentals of fish nutrition and diet development: An overview. Proceedings of the National Workshop on Fish Feed Development and Feeding Practices in Aquacuiture. FISON/NIFFR/FAO-NSPFS. 1–33.

Fagbenro O and Adebayo O. 2005. A review of the animal and aquafeed industries in Nigeria: A synthesis of the formulated animal and industry in sub-Saharan Africa. Rome: FAO.

Fagbenro O, Adeparusi E and Fapohunda O. 2003. Feed stuffs and dietary substitutions for farmed fish in Nigeria. Proceedings of the National Workshop on Fish Feed Development and Feeding Practices in Aquaculture. National Fresh Water Fisheries Research Institute. 60–65.

Falch Ø. 2014. Strong growth predicted for aquaculture: Shrimp and tilapia expected to more than double by 2030. Inocap: Oslo. https://admin.mekke.no/data/downloads/284/Fish2030-prospectsforaquaculture.pdf

[FAO] Food and Agriculture Organization. 2003. National aquaculture sector overview. Egypt. National aquaculture sector overview fact sheets. FAO Fisheries and Aquaculture Department. Rome: FAO.

[FAO] Food and Agriculture Organization. 2012. FAO global aquaculture production volume and value statistics database. Rome: FAO.

[FAO] Food and Agriculture Organization. 2016. The state of world fisheries and aquaculture 2016: Contributing to food security and nutrition for all. Rome: FAO.

[FAO] Food and Agriculture Organization. 2017. Fishery and aquaculture statistics: Global aquaculture production 1950–2015 (FishstatJ). FAO Fisheries and Aquaculture Department. Rome: FAO.

Farahiyah I, Zainal A, Ahmad A, Mardhati M, Thayalini K and Yong S. 2016. Evaluation of local feed ingredient-based diets on growth performance of African catfish, Clarias gariepinus. *Malaysian Journal of Animal Science* 19(2):39–46.

Fasahat P, Muhammad K, Abdullah A and Ratnam W. 2012. Proximate nutritional composition and antioxidant properties of 'Oryza rufipogon', a wild rice collected from Malaysia compared to cultivated rice, MR219. *Australian Journal of Crop Science* 6(11):1502.

Favre R and Myint K. 2009. An analysis of the Myanmar edible oil crops sub-sector. Rural Infrastructure and Agro-Industries Division. Rome: FAO.

Fowomola M. 2010. Some nutrients and antinutrients contents of mango (Magnifera indica) seed. *African Journal of Food Science* 4(8):472–76.

Francis G, Makkar HP and Becker K. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture* 199(3–4):197–227.

[GAFRD] General Authority for Fish Resources Development. Cairo: GAFRD. Accessed 12 December 2017. http://www.gafrd.org/

Gatlin DM, Barrows FT, Brown P, Dabrowski K, Gaylord TG, Hardy RW, Herman E, Hu G, Krogdahl Å and Nelson R. 2007. Expanding the utilization of sustainable plant products in aquafeeds: A review. *Aquaculture Research* 38(6):551–79.

Genschick S, Kaminski AM, Kefi AS and Cole SM. 2017. Aquaculture in Zambia: An overview and evaluation of the sector's responsiveness to the needs of the poor. Zambia: WorldFish and Department of Fisheries.

Ghose B. 2014. Fisheries and aquaculture in Bangladesh: Challenges and opportunities. *Annals of Aquaculture and Research* 1(1):1001.

Goldschmidt Jr A. 2008. A brief history of Egypt. Infobase Publishing.

Hamid N, Imra SN, Yusof M, Hanim SJ, Zakaria Z and Abdullah R. 2015. Evaluation of potential alternative ingredients for formulation of fish feed. *Applied Mechanics and Materials* 754:1081–86.

Hänninen A. 2014. On-farm Production and Utilization of Tilapia Feed. Programme for Luapula Agricultural and Rural Development – Phase II (PLARD II), Department of Fisheries (DoF), Zambia and Turku University of Applied Sciences, Finland. https://www.researchgate.net/publication/265301904_On-farm_Production_and_Utilization_of_Tilapia_Feed.

Hasan MR and New MB. 2013. On-farm feeding and feed management in aquaculture. FAO Technical Report. Rome: FAO.

Hecht T. 2007. Review of feeds and fertilizers for sustainable aquaculture development in sub-Saharan Africa. FAO Fisheries Technical Paper. Rome: FAO. 497:77.

Hossain M, Ahammad M and Howlider M. 2003. Replacement of fish meal by broiler offal in broiler diet. *International Journal of Poultry Science* 2(2):159–63.

Hossain M and Jauncey K. 1989. Nutritional evaluation of some Bangladeshi oilseed meals as partial substitutes for fish meal in the diet of common carp, Cyprinus carpio L. *Aquaculture Research* 20(3):255–68.

Hossain M, Sultana S, Shahriar S and Khatun M. 2012. Nutritive value of rice polish. *Journal of Animal Feed Research* 2:235–39.

Hossain ME, Sultana SA, Karim MH and Ahmed MI. 2015. Vegetable peels: A promising feed resource for livestock. *Journal of Animal Feed Research* 5:33–39.

Hossain MS, Kader MA, Dey T, Sony NM, Bulbul M and Koshio S. 2017. Effect of high inclusion of rendered animal by-product ingredients on growth, digestibility and economic performances in climbing perch Anabas testudineus. *Aquaculture Research* 48(3):931–40.

Ibiyo LMO and Olowosegun T. 2005. *On-farm feed: the potential for improving profitability in aquaculture*. In: 19th Annual Conference of the Fisheries Society of Nigeria (FISON) , 29 November–3 December 2004 ,Ilorin, Nigeria, pp. 45-53.

Jahan D, Hussain L, Islam M and Khan M. 2013. Comparative study of mustard oil cake and soybean meal-based artificial diet for rohu, Labeo rohita (Ham.) fingerlings. *The Agriculturists* 11(1):61–66.

Jahurul M, Zaidul I, Ghafoor K, Al-Juhaimi FY, Nyam KL, Norulaini N, Sahena F and Omar AM. 2015. Mango (Mangifera indica L.) by-products and their valuable components: A review. *Food Chemistry* 183:173–80.

Kabir J, Islam M, Ahammad M and Howlider M. 2005. Use of duckweed (Lemna minor) in the diet of broiler. *Indian Journal of Animal Research* 39:31–35.

Kaminski AM, Genschick S, Kefi AS and Kruijssen F. 2017. Commercialization and upgrading in the aquaculture value chain in Zambia. *Aquaculture* 493:355–64.

Kawsar M, Rashid M and Ali ME. 2001. Replacement of sesame oil meal by coconut oil meal in diets with or without fish meal on the performance of laying hen. *Journal of Biological Science* 6:516–18.

Khan M, Siddique M and Zamal H. 2013. Replacement of fish meal by plant protein sources in Nile tilapia (Oreochromis niloticus) diet: Growth performance and utilization. *Iranian Journal of Fisheries Sciences* 12(4):864–72.

Khandaker T, Khan MJ, Shahjalal M and Rahman MM. 2007. Use of duckweed (Lemna perpusilla) as a protein source feed item in the diet of semi-scavenging jinding layer ducks. *Journal of Poultry Science* 44(3):314–21.

Kumar V, Barman D, Kumar K, Kumar V, Mandal SC and De Clercq E. 2012. Anti-nutritional factors in plant feedstuffs used in aquafeeds. *World Aquaculture* 43(3):64.

Kwiri C, Muredzi P, Tongonya J, Gwala W, Mujuru F and Sha R. 2015. Mopane worm (Gonimbrasia belina) utilisation, a potential source of protein in fortified blended foods in Zimbabwe: A review. *The Global Journal of Science Frontier Research* 14(10):54-67.

Kyaw K. 2015. Development and use of alternative dietary ingredients for fish meal in Myanmar. Proceedings of the ASEAN Regional Technical Consultation on Development and Use of Alternative Dietary Ingredients or Fish Meal Substitutes in Aquaculture Feed Formulation, Nay Pyi Taw, Myanmar, 9–11 December 2014, 69–72.

Liong PC, Hanafi HB, Merican ZO and Nagaraj G. 1988. Aquaculture development in Malaysia. Seminar on Aquaculture Development in Southeast Asia, Iloilo City, Philippines, 8–12 September 1987. 73–90.

Loh T. 2004. Livestock production and the feed industry in Malaysia. FAO Animal Production and Health Proceedings. Rome: FAO.

Longhurst AR. 1961. Report on the fisheries of Nigeria. Lagos, Nigeria: Federal Fisheries Services, Ministry of Economic Development.

Lubungu M, Burke WJ and Sitko N. 2013. Analysis of the soya bean value chain in Zambia's Eastern Province. Lusaka, Zambia: Indaba Agricultural Policy Research Institute.

Lubungu M, Burke WJ and Sitko NJ. 2014. Analysis of the sunflower value chain in Zambia's Eastern Province. Michigan, USA: Michigan State University, Department of Agricultural, Food, and Resource Economics.

Makkar HP, Tran G, Heuzé V and Ankers P. 2014. State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology* 197:1–33.

Mamun-Ur-Rashid M, Belton B, Phillips M and Karim M. 2013. The current status of aquaculture and aquafeed production in Bangladesh. *World Aquaculture Magazine* 44(4):23–27.

Maqbool MA and Kerry B. 1997. Plant nematode problems and their control in the Near East region. Proceedings of the FAO Expert Consultation on Plant Nematode Problems and their Control in the Near East Region, Karachi, Pakistan, 22–26 November 1992.

Muin H, Fatah NNA, Nor MHM and Razak SA. 2013. Rice bran replacement in clarias gariepinus fingerlings diets with pleurotus florida stalk. *Sains Malaysiana* 42(8):1109–14.

Muin H, Taufek N, Kamarudin M and Razak S. 2017. Growth performance, feed utilization and body composition of Nile tilapia, Oreochromis niloticus (Linnaeus, 1758) fed with different levels of black soldier fly, Hermetia illucens (Linnaeus, 1758) maggot meal diet. *Iranian Journal of Fisheries Sciences* 16(2):567–77.

Murtuza G. 1998. The role of Bangladesh fisheries development corporation in development and harvesting of fish in Bangladesh. Sankalan, National Fish Week. Dhaka, Bangladesh: DOF. 6–8.

Mussatto SI, Dragone G and Roberto IC. 2006. Brewers' spent grain: Generation, characteristics and potential applications. *Journal of Cereal Science* 43(1):1–14. doi.org/10.1016/j.jcs.2005.06.001

Mwale M and Gwaze FR. 2013. Characteristics of duckweed and its potential as feed source for chickens reared for meat production: A review. *Scientific Research and Essays* 8(18):689–97.

[NACA/FAO] Network of Aquaculture Centres in Asia-Pacific and the Food and Agriculture Organization. 2004. Emerging trends and experiences in Asia-Pacific Aquaculture. Bangkok: NACA; Rome: FAO.

Neven D, Katjiuongua H, Adjosoediro I, Reardon T, Chuzu PN, Tembo G and Ndiyoi M. 2008. Food sector transformation and standards in Zambia: Smallholder farmer participation in the tomato sector. Michigan, USA: Michigan State University, Department of Agricultural, Food and Resource Economics.

Ng B. 2009. Current status and future prospects for the aquaculture industry in Malaysia. *World aquaculture* 40:26–30.

Ng W, Soe M and Phone H. 2007. Aquafeeds in Myanmar: A change from farm-made to factory-made feeds. *Aquaculture Asia* 12(3):7.

Nor N, Zakaria Z, Manaf M and Salleh M. 2011. The effect of partial replacement of dietary fishmeal with fermented prawn waste liquor on juvenile sea bass growth. *Journal of Applied Aquaculture* 23(1):51–57.

Norhidayah MT. 2016. Cricket meal as an alternative to fishmeal in diets for African catfish (Clarias gariepinus). Norhidayah Mohd Taufek, University of Malaya.

Obara J, Tun S and Htay T. 1974. Chemical composition of some concentrates available in Burma. *Nihon Chikusan Gakkaiho* 45(4):218–20.

Odunsi A. 2002. Effect of feeding reject cashew kernel meal on pre and early-laying performance of pullet. *Archivos de Zootecnia* 51(196):423–29.

Odunsi A. 2005. Response of laying hens and growing broilers to the dietary inclusion of mango (Mangifera indica L.) seed kernel meal. *Tropical Animal Health and Production* 37(2):139–50.

Ogugua N and Eyo J. 2007. Finfish feed technology in Nigeria. *Journal of Research in Bioscience* 3(1):23–39.

Omole A, Okpeze C, Salako R, Obi O and Fayenuwo J. 2013. Utilization of noodle waste as replacement for maize in the diet of broiler starter chickens. *American Journal of Experimental Agriculture* 3(4):1012.

Planning Commission. 2016. Seventh five-year plan (FY 2016–FY 2020), General Economics Division, Bangladesh Planning Commission. Government of People's Republic of Bangladesh. 283e291.

Raghavan V. 2000. Managing risks by the feed industry for safe food. The 22nd Malaysia Society of Animal Production (MSAP) Annual Conference, Kota Kinabalu, Malaysia, 29 May-1 June 2000. *In* Loh TC. 2002. Livestock production and the feed industry in Malysia. Proceedings of Protein Sources for the Animal Industry Expert Consultation and Workshop. Rome: FAO. 337–38.

Rahman M and Hossain M. 2013. Production and export of shrimp of Bangladesh: Problems and prospects. *Progressive Agriculture* 20(1–2):163–71.

Rahman ZA. 2012. Agricultural research and development in Malaysia. *Journal of International Society for Southeast Asian Agricultural Science* 18(2):22–33.

Rana KJ, Siriwardena S and Hasan MR. 2009. Impact of rising feed ingredient prices on aquafeeds and aquaculture production. FAO Fisheries and Aquaculture Technical Paper. Rome: FAO.

Razak IA, Ahmad Y and Ahmed E. 2012. Nutritional evaluation of house cricket (Brachytrupes portentosus) meal for poultry. 7th Proceedings of the Seminar in Veterinary Sciences, Universiti Putra, Serdang, Malaysia. 27 February–2 March 2012.

Ridzwan B, Fadzli M, Rozali M, Chin DT, Ibrahim B and Faridnordin B. 1993. Evaluation of cocoa-pod husks on performance of rabbits. *Animal Feed Science and Technology* 40(2–3):267–72.

Rohaida A, Alimon A and Sazili A. 2014. Fatty acid composition of breast and thigh muscles of broilers fed diets supplemented with candle nut kernel meal subjected to different heat treatments. *Malaysian Journal of Animal Science* 17(1):47–60.

Rosniyana A, Hashifah M and Norin SS. 2007. The physico-chemical properties and nutritional composition of rice bran produced at different milling degrees of rice. *Journal of Tropical Agriculture and Food Science* 35(1):99.

Ross S and de Klerk M. 2012. Groundnut value chain and marketing assessment in Eastern Province, Zambia. *Retrieved* 23(10):2013.

Saadiah I, Abol-Munafi A and Utama CC. 2011. Replacement of fishmeal in cobia (Rachycentron canadum) diets using poultry by-product meal. *Aquaculture International* 19(4):637–48.

San Mu K, Kasim AB, Ideris A and Saad CR. 2011. Effect of fermented rice bran, bio-converted byproduct on performance of broiler chickens. *Journal of Animal and Veterinary Advances* 10(22):2990–95.

Shamsuzzaman MM, Islam MM, Tania NJ, Al-Mamun MA, Barman PP and Xu X. 2017. Fisheries resources of Bangladesh: Present status and future direction. *Aquaculture and Fisheries* 2(4):145–56.

Shapawi R, Ng WK and Mustafa S. 2007. Replacement of fish meal with poultry by-product meal in diets formulated for the humpback grouper, Cromileptes altivelis. *Aquaculture* 273(1):118–26.

Sharmila A, Alimon A, Azhar K, Noor H and Samsudin A. 2014. Improving nutritional values of palm kernel cake (PKC) as poultry feeds: A review. *Malaysian Journal of Animal Science* 17(1):1–18.

Shipton T and Hasan M. 2013. An overview of the current status of feed management practices. On-farm feeding and feed management in aquaculture. FAO Fisheries and Aquaculture Technical Paper (583):3–20.

Shwe T and Kyu DKL. 2017. Groundnuts: Producing the good oil for Myanmar. *Partners in Research for Development* (2):28.

Simol CF, Tuen AA, Khan HHA, Chubo JK, King PJH and Ong KH. 2012. Performance of chicken broilers fed with diets substituted with mulberry leaf powder. *African Journal of Biotechnology* 11(94):16106–11.

Sogbesan A and Ugwumba A. 2008. Nutritional values of some non-conventional animal protein feedstuffs used as fishmeal supplement in aquaculture practices in Nigeria. *Turkish Journal of Fisheries and Aquatic Sciences* 8(1):159–64.

Sultana F, Khatun H and Ali MA. 2016. Use of potato as carbohydrate source in poultry ration. *Chemical and Biological Technologies in Agriculture* 3(1):30.

Tania H, Khan MA, Razia Khatun MR and Khalil I. 2009. An investigation on the nutritional composition of unconventional poultry feed resources. *Bangladesh Journal of Life Science* 21:21–28.

Udo I and Umanah S. 2017. Current status of the Nigerian aquafeed industry: A review. *International Journal of Innovative Studies in Aquatic Biology and Fisheries* 3(1):14–22.

[UNCTAD] United Nations Conference on Trade and Development. 2016. Cotton and its by-products sector in Zambia. Nairobi: UNCTAD.

[USDA] United States Department of Agriculture. 2017. The supply and demand for sugar in Zambia. Washington, D.C: USDA.

Van der Pijl W and van Duijn A. 2012. Myanmar seafood exports: Quick scan of the EU market potential. The Hague: CBI.

Wadhwa M and Bakshi M. 2013. Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products. *Rap Publication* 4:30.

Wan MS. 2015. Investigation of alternative ingredients for the replacement of fish meal in formulation of feed for Malaysian mahseer fingerlings, Tor Tambroides, Master Dissertation, Universiti Tunku Abdul Rahman (UTAR). Malaysia: UTAR.

Wassef E. 2005. Alternative protein sources for fish feeds in Egypt. *Cahiers Options Méditerranéennes* 63:114–27.

Wong HK. 2009. Conventional and novel sources of animal protein for poultry production. Animal Feedstuffs in Malaysia – Issues. Strategies and Opportunities. Academy of Sciences Malaysia. 75–93.

Yeong S and Faizah M. 1986. The effect of brewers grains on egg production in chiken. *MARDI Resource Bulletin* 14(1):81–84.

Yusuf SA. 2014. Role of agriculture in economic growth & development: Nigeria perspective. *Munich Personal RePEc Archive* MPRA paper No. 55536. http://mpra.ub.uni-muenchen.de/55536/

Zahari MW and Alimon A. 2004. Use of palm kernel cake and oil palm by-products in compound feed. *Palm Oil Developments* 40:5–8.

Zahari MW and Wong H. 2009. Research and development on animal feed in Malaysia. WARTAZOA. *Indonesian Bulletin of Animal and Veterinary Sciences* 19(4):172–79.

Zahari MW, Wong HK, Noraini S, Rahman A and Yusuf IMI. 2009. Processing of improved palm kernel cake and oil palm fronds as feeds for livestock. *National Conference of Agriculture and Food Mechanization* :47–49.

Zulkifli I, Ginsos J, Liew P and Gilbert J. 2003. Growth performance and Newcastle disease antibody titres of broiler chickens fed palm-based diets and their response to heat stress during fasting. *Archiv fur Geflugelkunde* 67(3):125–30.

Appendix 1. List of contacts and respondents during the course of the inventory.

Expert	Country	Medium	Useful information
Mike Phillips	Malaysia	Email, Skype	• Shared contact information for WorldFish representatives in most of these countries • Shared contact information for Patrik Henriksson • Provided general insights regarding the project
Patrik Henriksson	Sweden	Email, Skype	• Provided general insights on how to assess the environmental impacts of feed resources • Provided specific information on some of his projects on the life-cycle assessment of ingredients in Indonesia • Shared relevant documents in this regard
Kabir Kazi Ahmed, Rashid Mamun, Mohammad Baten	Bangladesh	Email, Skype	• Provided general information on the status of aquafeed in Bangladesh • Shared documents on some nonconventional feedstuff in Bangladesh • Assisted with travel logistics to Bangladesh
Karim Manjurul	Myanmar	Email, Skype	• Provided general insights on aquaculture and aquafeed in Myanmar • Promised to send relevant documents • Helped with travel logistics
Suri Sharon	Malaysia, Indonesia, Tanzania	Email, Skype	• Provided information on WorldFish activities ongoing in Malaysia, Indonesia and Tanzania • Shared contact information for Nazael Madalla
Nurul-Ahmad Fatan	Malaysia, Indonesia	Email, Skype	• Provided general information on aquafeed in Indonesia and Malaysia • Shared relevant documents on both aquaculture feeding and management in Malaysia and Indonesia
Nazael Madalla	Tanzania	Email	• Answered questions on the status of aquaculture in Tanzania • Ready to assist for further information
Karisa Harrison	Egypt	Email, Skype	• Gave more insights on aquafeed in Egypt • Promised to send relevant documents on previously conducted work by WorldFish in Egypt • Aided with travel logistics • Shared contact information for other stakeholders in Egypt
Steven Cole	Zambia	Email, Skype	• Shared general perspectives on the status of feed resources in Zambia • Ready to assist with interviewing stakeholders • Helped with travel logistics
Sven Genshick	Kenya	Email	• Helped with contact information for experts working on similar projects in Kenya, including Charles Opanga • Skype discussion in the pipeline
Charles Opanga	Kenya	Email, Skype	• General perspectives of aquaculture feed ingredients in Kenya • Promised to share relevant documents • Shared contact information for the Lenalia Feed company (local Kenyan feed company focusing on hydrolyzing feather for animal feed)
Mahmoud Farahat	Nigeria (Olam group)	Email	• Provided information on locally available feed ingredients for poultry feed in Nigeria

Table 47. Contact list of various experts, during the course of the inventory, and relevant information obtained through Skype and email.

Expert	Country	Affiliation	Useful information
Aung Tun Aye	Bangladesh	Agro-solution (feed nutrition and process management)	• Assists in collecting relevant information in Bangladesh
Osama Solimon and Seif Omar	Egypt	Cargill	• Cargill crushes soybean in Egypt • Imports soybean meal • Egypt produces soybean, but the pods are of lesser quality and therefore produce low quality oil
Aymen Rostom and Alaa Badr	Egypt	Skretting	• Provided an overview of the Egyptian feed industry • Nearly all feed ingredients are imported into Egypt
Reda Zakia	Egypt	Small feed miller	• Discussed the major feed ingredients used in Egyptian aquaculture • Currency fluctuation affects the price of ingredients • Local soybean meal is used by some of the feed millers
AbdulHammad Atia	Egypt	Medium-scale feed miller	• Provided a general overview of the Egyptian feed industry • Some ingredients (such as nut cake) can be imported from Sudan • Algae is a potential ingredient but is currently produced in low quantities • Feather meal and poultry meal can also be explored
Rhaman Khattab	Egypt	Al-aqua	• Discussed alternative ingredients available in Egypt
Ben Belton	Myanmar	Michigan State University	• Provided overview and challenges facing aquaculture industry in Myanmar
Don Griffiths	Myanmar	WorldFish	• Provided overview and challenges facing aquaculture industry in Myanmar
Fagbenro Dapo	Nigeria	FUTA, Akure	• Discussed Nigerian aquaculture (discussion to continue during a later visit to Nigeria)
Tunde Adegoke Amole	Nigeria	ILRI, Ibadan	• Discussed prospects of cassava peel as a fish feed ingredient

Table 48. Contact list for various experts.

Name	Gender	Affiliation	Location
Feed manufacturers			
Tusher Sarker	Male	-	Chitalmari, Bagerhat
Bidan Biswas	Male	-	Mollarhat, Bagerhat
Md. Hasanuzzasman	Male	-	Paikhgacha, Khulna
SK Mustafigzur Rahman	Male	-	Kachua, Bagerhat
Mohammad Khasru	Male	SMS Feeds Ltd	Dhaka
SK Hemyeth Uddin	Male	Bismillah feed Ltd	Bagerhat
Sheikh Nur Islam	Male	Fakirhat Feed Mill	Fakirhat, Bagerhat
Habibullah Seheikh	Male	-	Khulna,
Shafiqul Islam	Male	Afil Fish Feed Ltd	Jessore
Mrianl kanti Deb	Male	Paragon Feed Ltd	Gazipur
Asadullah Galib	Male	Bangla Feed Ltd	Rajshahi
Md. Mokarrum Hossain	Male		Trisal, Mymensingh
-	-	MARS Feed Mill	Muktagacha, Mymensingh
-	-	Arab Feed Mill	Muktagacha, Mymensingh
Md. Omar Farque	Male	-	Trisal, Mymensingh
Mohammad Emdadul Hoque	Male	Nil Shagor Agro Industries	Niphamari
Md. Shahinur Alam	Male	RB Agro Industries	Bogra
Md. Rafiqul Islam	Male	KNB Feed Ltd	Kustia
Sonkor	Male	Agata Feed Mills Ltd	Comilla
Md. Abdul jalil khan	Male	Toyo Feed	Gazipur
Nishit Kuner mondal	Male	Lion Feed Limited	Gazipur
-	-	SB Agro industries	Norshindi
Fish farmers			
Panchanan Biswas	Male	-	Mollarhat, Bagerhat
Zagosh Mukssi	Male	-	Mollarhat, Bagerhat
Uttam Howlader	Male	-	Mollarhat, Bagerhat

Name	Gender	Affiliation	Location
Bhuban Mondal	Male	-	Mollarhat, Bagerhat
Baloram Howlader	Male	-	Chitolmari Bagerhat
Md. Ibrahim Khandaker	Male	-	Norshindi
Bivas Roy	Male	-	Mollarhat, Bagerhat
Ronzit Chintapatro	Male	-	Mollarhat, Bagerhat
Harida Mozumder	Male	-	Mollarhat, Bagerhat
Anias Podder	Male	-	Fakirhat, Bagerhat
Ashini Kha	Male	-	Mollarhat, Bagerhat
Asuthush Mozumder	Male	-	Mollarhat, Bagerhat
Sarder Mozaffor	Male	-	Chitolmari, Bagerhat
Debasis Biswas	Male	-	Chitolmari, Bagerhat
Ingredient suppliers			
Md. Zafor	Male	Gousia Traders	Kalibari, Khulna
Awalad Hossain Matbar	Male	Matbar Traders	Uttara, Dhaka
Md. Shajahan Bhuyain	Male	Mehedi Traders	Dhaka
Zahangir Alam	Male	Zahangir traders	Dhaka
Asis Kunur Ghosh	Male	-	Fakirhat Bagerhat
Ahsan Monir (Mukta)	Male	Master Seed House	Fakirhat Bagerhat
Jashim Uddin Maral	Male	Shajalal Traders	Fakirhat Bagerhat
Shapon Kumar Saha	Male	Saha Traders	Bagerhat
Zahirul Islam	Male	Madina Poultry	Savar
Subir Hossain	Male	MS Trading	Dhaka
Mahabubur Rahman	Male	Biswas Poultry	Dhaka
Nazmul Hoque	Male	-	Rajshahi
Ratul	Male	-	Rajshahi
Mr. Rashed	Male	-	Trisal, Mymensingh
Tofail Ahmed	Male	-	Trisal, Mymensingh
Rezaul Islam	Male	-	Pirgong, Takurgaoh

Table 49. List of respondents interviewed in Bangladesh.

Respondent (or company) name	Gender	Location
Feed manufacturers		
ElMohandeseen	Male	Al Buhaira
My Feed	Male	Al Buhaira
The Brathers	Male	Kafr El Sheikh
Elsaad	Male	Kafr El Sheikh
International Feed Company	Male	Kafr El Sheikh
Elamana	Male	Kafr El Sheikh
El Nor	Male	Kafr El Sheikh
Aller Aqua Egypt	Female	Giza
Skretting Egypt	Male	10th of Ramadan
El-Ethad	Male	Ismailia
EL- Asad	Male	Al Buhaira
El-Manzala	Male	Dakahlia
EL-Morshedy	Male	Dakahlia
EL-Marwa	Male	Kafr El Sheikh
EL-Gharbia for Feed	Male	Kafr El Sheikh
Feed ingredient suppliers		
Cargill	Male	Alexandra
Manfaz	Male	Giza
Elmagd	Male	Menoufia
Mohamed Hafaga	Male	Kafr El Sheikh
El Owysia	Male	Dakahlia
Fish farmers		
Rashed	Male	Al Buhaira
Mohamed Saad	Male	Al Buhaira
Osama Ahmed	Male	Al Buhaira
Abd Elhamed Hussein	Male	Kafr El Sheikh
Hany Saleh	Male	Al Buhaira
Ahmed Essam Ahmed	Male	Ismailia
Khalil Saad	Male	Ismailia
Ashraf Sheha	Male	Al Sharqiya
Samir Helmy	Male	Al Sharqiya
Ashraf Abd El-Azziz	Male	Al Sharqiya
Mohamed Ghozy	Male	Al Sharqiya
Ali Elhadeedy	Male	Al Sharqiya
Sayed Saad	Male	Al Sharqiya
Mohamed Elbaz	Male	Al Sharqiya
Elsayed khedr	Male	Port Said
Sayed Abo Zaid	Male	Port Said
Magdy Abo Omar	Male	Al Sharqiya

Respondent (or company) name	Gender	Location
Fish farmers		
Mohamed Etman	Male	Port Said
Gamal Saiad	Male	Port Said
Samy Brmo	Male	Al Buhaira
Omar Deabis	Male	Al Buhaira
Abdo Elbendary	Male	Kafr El Sheikh
Mohamed Abd-Elrahman	Male	Al Sharqiya
Elsayed Elhosry	Male	Ismailia
Mohamed Ahmed	Male	Ismailia
Mohamed Mousa	Male	Port Said
Shaker Elezaby	Male	Port Said
Al-Sadat Rahma	Male	Al Sharqiya
Ahmed Alsoyarky	Male	Al Sharqiya
Elsayed Abo Abbacc	Male	Al Sharqiya
Sayed Warda	Male	Al Sharqiya
Saad Abu Jahl	Male	Al Buhaira
Nabil Ahmed	Male	Al Buhaira
Emad Hamdi	Male	Kafr El Sheikh
Jamal Mowafi	Male	Kafr El Sheikh
Abd Elrasol Elkarb	Male	Kafr El Sheikh
Sobhi Hussein	Male	Kafr El Sheikh
Safwat Rashwan	Male	Kafr El Sheikh
Ali Abo Elanain	Male	Kafr El Sheikh
Ebrahim Abbas Nmais	Male	Kafr El Sheikh
Ghanem Hassan Bramy	Male	Al Buhaira
Mahmoud Elragal	Male	Al Buhaira
Maher Ali Abd Elsattar	Male	Kafr El Sheikh
Sayd Abdel Aal Ebrahim	Male	Kafr El Sheikh
Mohamed Hamdy	Male	Ismailia
Hassan Naim	Male	Ismailia
Khaled Khalefa	Male	Kafr El Sheikh
Ahmed Arban	Male	Kafr El Sheikh
Ahmed Shaban	Male	Al Buhaira
Elsayed Ghanem	Male	Al Buhaira
Mohamed Abu Elnaga	Male	Al Buhaira
Aref Ahmed Zyton	Male	Al Buhaira
Hany Glo	Male	Kafr El Sheikh
Mohamed Glo	Male	Kafr El Sheikh
Smarah Aynos	Male	Al Buhaira

Table 50. List of respondents interviewed in Egypt.

Name	Company	Gender	Location
Mike Fula	Kafue Fisheries	Male	Kafue
Donne	AFGRI Corporation	Male	Lusaka
Eckhard Kern	Farm Feed General Manager	Male	Lusaka
Douglas	Southern Chickens	Male	Lusaka
Keith Mwenya	Small Scale Farmers Hub	Male	Lusaka
Daminan Roberts	Capital Fisheries	Male	Lusaka
Devinder Chadha	Quality Commodities	Male	Lusaka
Musa Masood	Crown Millers	Male	Lusaka
Alok Dikshit	Export Trading Co. Ltd (ETG)	Male	Lusaka
Gaureshkumar Rana	Mount Meru	Male	Lusaka
Christian Morris	NWK	Male	Lusaka
Mark Kernick	Yalelo Operation Manager	Male	Siavonga
Leo	Aller Aqua CEO	Male	Siavonga
Farayi Muzofa	Aller Aqua	Male	Siavonga
Yvonne Mwanza	Kariba Harvest Lake manager	Female	Siavonga
Abraham Swanepoel	Skretting	Male	Siavonga

Table 51. List of respondents interviewed in Zambia.

Name	Gender	Affiliation	Location
Fish farmers			
Bakare Yusuf	Male	Acumen Enterprise	Osogbo
Ibrahim Idowu	Male	Tuns Farm	Osogbo
Olaleye Oluwasogo	Male	-	Osogbo
Saheed Sulaiman	Male	-	Osogbo
Adefowoju Abu Hafiz	Male	integrated farm	Oyo
Ipadeola Emmanuel	Male	-	Oyo
Oguniyi Mathew	Male	-	Oyo
Salau Musa	Male	-	Oyo
Tiamiyu Nurudeen	Male	Amolese Aquaculture	Lagos
Deepak Nagpal	Male	Nine Star Integrated Services Ltd	Sagamu
Feed producers			
Raji Adebayo	Male	Amo Byng Nigeria Ltd	Oyo
Oladimeji Sabur	Male	Amo Byng Nigeria Ltd	Oyo
Hawwal Sekim	Male	Amo Byng Nigeria Ltd	Oyo
Harry Folami	Male	Agro-Allied Processing Enterprise	Oyo
-	Male	Neatdollars Feedmill	Oyo
-	Male	Mosodun Feedmill	Osogbo
Babatunde Adewale	Male	Timreb Feedmill	Osogbo
Benjamin Adeboye	Male	Ace Feed Ltd.	Osogbo
Olufemi Osuolale	Male	Skretting Nigeria	Ibadan
Adedeji Omotayi	Male	Skretting Nigeria	Ibadan
Dipo Ogunlana	Male	Skretting Nigeria	Ibadan
Segun Ajayi	Male	Crown Flour mill (Olam group)	Lagos

Table 52. List of respondents interviewed in Nigeria.

Appendix 2. Survey questionnaires

Feed manufacturer questionnaire.

1. Name

2. Location (city/county/district/state/governorate)

3. Ownership (private/public)

4. What is the annual capacity of the feed mill?

5. Type of animal feed produced

   Poultry ( ) Pig ( ) Fish ( ) Ruminant ( ) Other ( ) If other, please specify.

6. What is the percentage of fish feed from the total annual feed production?

7. What type of fish feed do you produce (pelleted, extruded, both)?

8. What type of fish species do you produce feed for?

Fish species	% of total annual feed ingredients used	Annual production (t)	Annual sales (t)

9. Please list feed ingredients.

Common name	Local name	Source	If both, % of each	Amount (t/year)	Price/t	% CP	% Lipid

10. How do you conduct your chemical analyses?

    Yourself ( ) Contracted ( ) Other ( ) If other, please specify.

    ____

    How often do you conduct these chemical analyses in a year?

    ____

11. If by yourself, which of these methods do you always use?

    Laboratory ( ) NIR ( ) Other ( ) If other, please specify.

    ____

12. Do you validate the quality of the ingredients received from your suppliers upon arrival at your feed mill?

    Yes ( ) No ( ) If yes, how do you conduct it?

    ____

13. How do you store your feed ingredients?

____

What is the capacity of your storage facility?

____

What quality control tests/measures do you conduct on the ingredients while in storage?

____

14. How have prices of feed ingredients changed compared to previous years?

Increased ( )   Decreased ( )   Stable ( )

What factors are responsible for the price change?

____

15. Please list any possible constraints.

S/N	Ingredient name	ANFs	Mycotoxins	Other
1				
2				
3				
4				
5				

16. In case of presence of ANFs, mycotoxin or other impediments, how do you get rid of them?

____

17. Do you receive incentives or benefits in any form from the government or an external financier?

Yes ( )   No ( )

If yes, please specify.

____

____

18. What percentage of your operating cost is taken up by the feed ingredients?

___

19. Do you export your feed to any foreign country?

Yes ( ) No ( )

___

If yes, please specify which countries and the percentage of exported feeds out of your total annual production.

___

___

20. Do you have any trade union regulating the price of ingredients?

Yes ( ) No ( )

21. If yes, please specify and explain how efficient they are.

___

___

22. When buying feed ingredients, what are the major problems you face in terms of price, quality and availability?

___

___

23. Do you face any general problems? Do you have any future plans to increase production in your feed mill?

___

___

___

24. Do you have any other comments regarding the feed industry in your country?

___

___

Fish farmer questionnaire.

1.1 Name

____

1.2

1. Location (town/city/district/county/governorate)

____

2. Ownership (public/private/cooperative/other)

____

3. What is the size of your farm?

____

4. Where do you culture your fish?

   Earthen ponds ( )   Concrete tanks ( )   Cages ( )   Other ( )   If other, please specify.

____

5. What type of farming systems do you practice?

   Extensive ( )   Semi-intensive ( )   Intensive ( )   Other ( )   If other, please specify.

____

6. What type of water do you use on your farm?

   Freshwater ( )   Brackish ( )   Marine ( )   Other ( )   If other, please specify.

____

7. What fish species are cultured in your farm?

Species	Sexes	Stocking number	Stocking size (g/fish)	Culture period (month)

8. Do you use fertilizer on your farm?

Yes ( ) No ( )

If yes, which type of fertilizer?

Organic ( ) Inorganic ( )

Please specify the name of the fertilizer.

____

9. Do you use commercial fish feeds?

Yes ( ) No ( )

If yes, which type of feed?

Extruded ( ) Pelleted ( ) Both ( ) Farm-made ( )

Where do you buy your feeds from?

Feed mill ( ) Wholesaler ( ) Retailer ( ) Other

____

10. If you make your feed on-farm, where do you get your ingredients from?

Feed mill ( ) Feed supplier ( ) Other ( ) If other, please specify.

11. What ingredients are needed for on-farm feeds?

Ingredient	Source	Price/t	% CP (if known)	% Lipid (if known)

12. What processing methods do you adopt during feed preparation?

    Drying ( ) Grinding ( ) Cooking ( ) Other ( ) If other, please specify.

    ____

    ____

13. How do you know whether the farm-made feeds have met the requirements of the fish?

    ____

    ____

14. In what form do you give feed produced on the farm to your fish?

    ____

15. What is the reason for preparing your fish feeds on the farm?

    Size of the farm ( ) Cost-effectiveness ( ) Other ( ) If other, please specify.

    ____

16. Has there been any change in the price of ingredients compared to previous years?

    Increased ( ) Decreased ( ) Stable ( )

    Can you state the reason for the price change?

    ____

17. How do you pay for your ingredients?

    Cash ( ) Loan ( ) Credit ( ) Other ( ) If other, please specify.

    ____

18. What is the price per metric ton of farm-made feed?

    ____

19. What feeding methods do you apply?

    ____

20. How do you store your ingredients (and feeds) and prevent them from deteriorating?

    ____

21. When buying feed ingredients, what are the major problems you face in terms of price, quality and availability?

    ____

22. Do you receive any incentives from the government?

Yes ( ) No ( )

If yes, please describe.

____

____

23. Do you need any training or capacity building programs regarding fish feeding as well as overall aquaculture management?

____

____

24. Do you have any general comments regarding fish feed and feeding management?

____

____

Feed ingredient supplier questionnaire.

1. Name

____

2. Location (city/town/county/governorate/state)

____

3. Ownership (public/private/cooperative/other)

____

4. Which kind of customers do you supply ingredients to?
   Livestock farmers ( ) Feed mills ( ) Both ( ) Other ( ) If other, please specify.

____

5. If feed mill, what is the capacity of the feed mill?
   Large-scale ( ) Small-scale ( ) Medium-scale ( ) Other ( ) If other, please specify.

____

6. If livestock farmers, which types of animals are they producing?
   Poultry ( ) Fish ( ) Pigs ( ) Ruminants ( ) Other ( ) If other, please specify.

____

7. What percentage of your total annual supply goes to fish farmers?

____

8. Please list your annual feed ingredients inventory.

Ingredient	Local name	Source	Availability	Price/t	Annual purchase (t)	Annual sales (t)

9. How do you store the feed ingredients before selling them to your customers?

____

10. What is the capacity of your storage facility and how do you prevent the ingredients from deteriorating?

____

11. What measures do you take to determine the quality of the supply of ingredients to your company?

____

12. Do you conduct nutrient composition of these ingredients? Yes ( ) No ( )

____

If yes, how do you carry it out?

Yourself ( ) Contracted ( ) Both ( ) Other ( ) If other, please specify.

If by yourself, what methods do you always use?
Laboratory ( ) NIR ( ) Both ( ) Other ( ) If other, please specify.

____

Ingredients	% CP	% Lipid	ANFs	Mycotoxin

13. Do you also sell some of these ingredients for potential human consumption? If yes, what ingredient(s) and what percentage of your annual sales?

Ingredient	% of annual sales for food

14. When buying feed ingredients, what are the major problems you face in terms of price, quality and availability?

____

15. When selling feed ingredients, what are the major problems you face in terms of price, quality and customer demand?

____

16. What other bottlenecks affect conducting your business effectively?

____

17. Do you receive incentives in the form of loans, credit, subsidies, etc., from the government or any private institutions?

____

Appendix 3. Summary of ingredients for future research

Ingredient	Bangladesh	Myanmar	Malaysia	Egypt	Nigeria	Zambia
Protein sources						
Soybean meal	✓	✓	✓	✓	✓	✓
Rape and mustard oil cakes	✓					
Sesame cake	✓	✓		✓	✓	
Groundnut cake	✓	✓		✓	✓	✓
Coconut meal	✓		✓		✓	
Palm kernel cake			✓		✓	
Sunflower seed cake		✓	✓	✓		✓
Cotton seed meal				✓	✓	✓
Dry fish	✓		✓	✓	✓	
Shrimp/prawn meal	✓	✓	✓	✓	✓	
Squid meal		✓				
Feather meal	✓	✓	✓	✓	✓	✓
Poultry meal	✓			✓	✓	✓
Blood meal	✓	✓		✓	✓	✓
Energy and fiber sources						
Rice bran	✓	✓		✓	✓	✓
Wheat bran	✓	✓		✓	✓	✓
Maize meal	✓	✓	✓	✓	✓	✓
Maize bran	✓	✓	✓		✓	
Cassava peel and leaf	✓		✓		✓	✓
Sugarcane/beet pulp	✓			✓	✓	✓
Khesari seed	✓					
Potato peel	✓					✓
Pineapple pulp	✓					
Mango kernel	✓				✓	
Gram bran		✓				
Brewers' waste			✓		✓	✓
Sago pith meal			✓			
Cocoa husk meal			✓			
Rubber seed meal			✓			
Flaxseed meal				✓		
Barley meal				✓		

Ingredient	Bangladesh	Myanmar	Malaysia	Egypt	Nigeria	Zambia
Energy and fiber sources						
Sorghum meal				✓	✓	✓
Date seed meal				✓		
Tomato fruit waste				✓		✓
Cocoa reject meal					✓	
Noodles and biscuit waste					✓	
Cashew reject meal					✓	
Millet meal					✓	✓
Cowpea seed meal					✓	
Cocoyam leaf and peel					✓	
Yam peel					✓	
Lipid sources						
Soybean oil	✓	✓		✓	✓	✓
Mustard oil	✓					
Rice bran oil	✓					
Coconut oil			✓		✓	
Fish oil					✓	
Sesame oil	✓	✓		✓		
Groundnut oil	✓	✓	✓	✓	✓	✓
Palm oil			✓		✓	
Sunflower oil		✓	✓	✓		✓
Squid oil		✓				
Maize oil					✓	
Vegetable oil					✓	
Cotton seed oil				✓	✓	✓

Table 53. Summary of ingredients (current and potential) available in the focal countries, based on secondary data for each country.

Appendix 4. Stakeholder matrix

SN	Stakeholder	Types of organization	Activities	Possible constraints
1	WorldFish	CGIAR consortium (nongovernmental organization)	• Coordinates research activities on sustainable fish feeds • Works closely with relevant stakeholders in respective countries	-
2	ILRI	CGIAR consortium	• Works on cassava and other crop residues that can be used as fish feed	-
3	IITA	CGIAR consortium	• Works on improving crop productivity for human and animal use	-
4	Government	Local, state and federal Department of Aquaculture and Fisheries	• Provides incentives such as credit and subsidy facilities • Creates an enabling environment for research programs • Enacts laws and legislations	Vested interest; infrastructural deficit; lack of political will
5	Fish farmers	Private individuals, government owned, private companies	• Buy feed ingredients • Buy feeds • Produce fish	Low capital outlay; market constraints
6	Feed ingredient suppliers	Private companies, small-scale individuals	• Sell ingredients for aquafeed	Limited aquafeed ingredients
7	Feed manufacturers	Producers and sellers of aquafeed	• Produce and sell aquafeed	High production costs
8	FAO	Nongovernmental organization	• Synergizies with WorldFish on the development of aquaculture	-
9	Local NGOs	Nongovernmental organizations	• Create services to communities • Help farmers and other stakeholders	-
10	Small- and large-scale crop producers	Private, government, individuals	• Produce ingredients of crop origin	Low capital output; disease infection and pest infestation; market instability
11	Livestock farmers and processors	Individuals, farmers, government	• Produce by-products for aquafeeds	Insufficient capital
12	Fruit processors	Individuals, private companies	• Produce by-products for aquafeeds	Handling of fruit waste
13	Breweries	Private, government	• Supply brewer waste for aquafeed	Handling of brewery waste

Table 54. Stakeholders to partner with in different countries.

RESEARCH PROGRAM ON Fish

Led by WorldFish

About FISH

Pursuing a research agenda through a network of multistakeholder partners, the CGIAR Research Program on Fish Agri-Food Systems (FISH) enhances the contributions of fisheries and aquaculture to reducing poverty and improving food security and nutrition. FISH is led by WorldFish, together with the ARC Centre of Excellence in Coral Reef Studies at James Cook University, Australia; the International Water Management Institute (IWMI); Natural Resources Institute (NRI) at the University of Greenwich, England and Wageningen University & Research (WUR), Netherlands. In regional contexts, the program partners closely with governments, NGOs, the private sector and research organizations to influence national, regional and global policy and development practice.

For more information, please visit fish.cgiar.org