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Research Article

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Commercial Aquafeed Production and Usage in Zambia: Reviewing its Current Status, Developmental Constraints and Opportunities

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Abstract

This review analyses the challenges and opportunities of using commercially produced aquafeeds in Zambia for tilapia cultivation, considering population growth, income, and cultural preferences, while also highlighting potential advantages. High-quality aquafeed is essential for optimal growth, feed conversion efficiency, and fish health, promoting increased utilization in the country. The establishment of modern facilities by Skretting, Aller Aqua, and Novatek is having a positive impact on Zambia's fish feed production. These companies are dedicated to achieving a sustainable balance between commercial expansion and smallholder development, while also fostering growth in the aquaculture value chain. Challenges such as substandard feed production, rising costs, limited access to affordable raw materials, and insufficient funding are being faced by the industry. These obstacles have the potential to significantly influence the industry's growth and economic contribution.

Keywords: *Commercial Aquafeed; Production; Zambia; Current Status; Constraints; Opportunities*

Introduction

Fish transitioning from natural to artificial habitats requires adequate nourishment for growth. The feed should meet the nutritional requirements of cultured fish, as stated by Munguti *et al*., (2014). Fish diets are either comprehensive with artificial feeds or supplemented with natural foods (Eyo, 2003; Ogugua and Eyo, 2007).

Intensive fish farming heavily relies on prepared feed for nutrients and energy, including protein, vitamins, and minerals, to support fish growth and physiological functions (Ogugua and Eyo, 2007; Zenopelletmachine.com; Aizama et al., 2018). Genschick et al. (2017), emphasize the significance of feed quality and availability in Africa's aquaculture development, emphasizing the need for resource allocation and regulatory establishment for optimal growth (ISU, 2014;

Das, 2014). The quality, safety, and nutritional benefits of farmed fish necessitate meticulous analysis and formulation of fish feed using the appropriate combination of ingredients (Singh, 2020; Firew Admasu, 2021).

Materials and Methods

In this study, the production and utilization of aquafeed in Zambia was thoroughly examined. The analysis was based on reports from FAOSTAT and peer-reviewed literature. The study placed particular emphasis on protein sources, animal feed, ichthyology, nutrition, and aquaculture.

Results and Discussion

Status and Trends of Aquaculture Production

The expansion of aquaculture in the country can be attributed to the use of high-quality seeds, commercial feeds (Genschick et al., 2017; Mwema *et al*., 2021), effective management techniques, and skilled labour on farms, leading to increased productivity as highlighted in the reports by VCA4D, 2018, PMRC, 2018, and Maulu *et al*., 2019. Moreover, the adoption of modern approaches has played a crucial role in driving this growth, as traditional methods have been proven inadequate, as indicated by Kefi's research in 2023.

Fish feeds play a vital role in the growth, well-being, and reproduction of cultured fish. They contain essential elements such as water, proteins, lipids, carbohydrates, vitamins, minerals, and pigments (Vipinkumar *et al*., 2019). Artificial feeds offer advantages such as increased stocking density, faster growth, and the ability to act as biodegradable fertilizer. However, small-scale farmers often face the challenge of high costs, making the adoption of these feeds a costly choice (CCPC, 2019).

Fish production opportunities are available in the country's primary aquaculture facilities, including cages, ponds, and smaller water bodies, particularly in the Southern and Eastern provinces, according to reports from FAO in 2022 and MFL in 2023. The private sector's interest in tilapia cage culture has been sparked by its success in increasing production on Lake Kariba (Kaminski et al. 2018). The utilization of cage culture is gaining popularity among large-scale commercial fish farmers and innovative individuals, leading to a rise in the number of major fish farms in Copperbelt, Lusaka, and Southern Provinces from 15 to 20.

Zambia is now regarded as a success story in boosting aquaculture production in Southern Africa (Moyo and Rapatsa, 2021). It has become the sixth-largest farmed fish producer in Africa, with a production of 75,500 tons in 2022. This growth is a positive indication for the future of aquaculture production, as stated by FAO, MFL, and Kefi in 2022 and 2023.

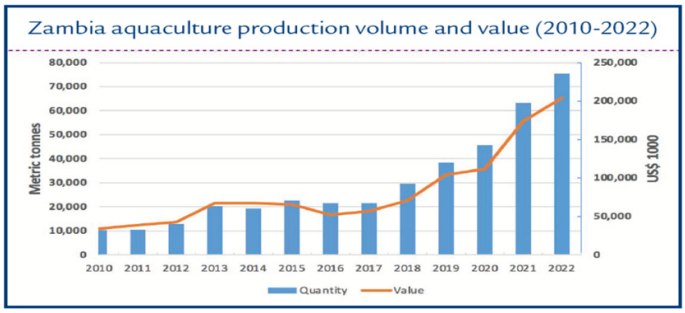

Figure 1: *Growth of aquaculture in Zambia (Source: FAO and Ministry of Fisheries and Livestock).*

In Zambia, five species of tilapia have been adopted by the local population, with one being foreign and the remaining four being native. These species include Nile (*Oreochromis niloticus*), three-spotted (*Oreochromis andersonii*), Green-headed (*Oreochromis macrochir*), Red-breasted (*Coptodon rendalli*), and Tanganyika (*Oreochromis tanganicae*) species (Hasimuna *et al*., 2023).

Zambia's aquaculture sector is primarily driven by the Nile tilapia, surpassing the three-spotted tilapia in popularity due to its ability to withstand colder temperatures. This resilient species now accounts for 60% of the country's total aquaculture production. Notably, *O. niloticus*, which has been successfully introduced in Zambia, exhibits an impressive growth rate, reaching a weight of 1000 g within a span of 12 months (Moyo *et al*., 2021; FAO, 2022). Although genetically improved species are not currently being cultivated in Zambia, *O. niloticus* has undergone sex reversal manipulation in the past (FAO, 2022). This has led to the development of aquaculture techniques and the establishment of private hatcheries specializing in producing Nile tilapia fingerlings in Zambia (CCPC, 2019).

Zambia's government acknowledges the importance of diversifying income and nutrition sources, promoting aquaculture for future growth and employment, meeting protein requirements (FAO, 2022). The country's fish demand is expected to surpass 300,000 tons by 2025, with imports increasing 56.3% between 2014 and 2016 (MCTI, 2020; Mwema *et al*., 2021).

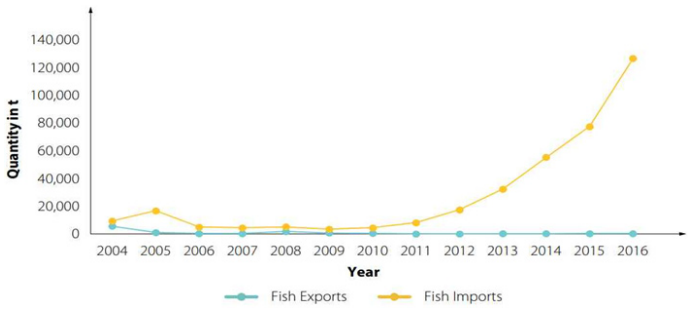

Figure 2: *Formal fish exports and imports from 2004 to 2016 (Source: Zambia Revenue Authority Cross-Border Fish Trade Records).*

The aquaculture sector experienced significant employment growth over three years, from 12,019 in 2016 to nearly 36,000 in 2019, according to the FAO in 2022.

The potential benefits and opportunities that can be achieved through the use of commercially produced aquafeed

According to a recent study by Hasimuna *et al*. (2023), the majority of national aquaculture production, amounting to 75%, is supplied by large-scale commercial producers. Small-scale producers only contribute 25% to annual production, with feed cost being a key factor affecting production costs. Through the utilization of commercially manufactured aquafeed, there exists a multitude of potential benefits and opportunities that can be realized. Feeding represents the paramount aspect in aquaculture, as well as in other aquaculture systems (Korkut et al., 2016). The cost of fish feed alone constitutes 70% of production expenses, underscoring the significance of employing effective feed formulation practices (Korkut et al., 2016; Firew Admasu, 2021).

The profitability and sustainability of aquaculture greatly depend on the availability of high-quality and cost-effective feeds (ISU, 2014). Therefore, it is crucial to invest in and regulate the production of high-quality feed to ensure the growth and sustainability of fish (Firew Admasu, 2021).

In order to ensure a substantial yield of fish for the market, it is imperative to have easily accessible high-quality complete feed for the cultured fish species (ISU, 2014). The nourishment of living organisms, driven by feeding, plays a pivotal role in determining all vital activities within a living organism. Hence, the provision of complete fish feed pellets, which encompass all necessary nutrients, becomes indispensable (ISU, 2014). In addition to its significance for the biological makeup of life, feeding also exhibits a remarkable impact on production cycles and expenses (Korkut *et al*., 2016).

Fregene *et al*. (2020), suggest that fish thrive on a diet containing 20-30% crude protein, with 2-10% derived from animal sources. The use of high-quality commercial feeds by fish farmers typically results in improved productivity compared to those who rely on single ingredients, which can lead to stunted growth and lower productivity.

Mwango *et al*.'s (2016) study revealed that introducing commercial feed in the Copperbelt and North-western Provinces significantly improved the productivity of farmers. In fact, utilizing this product resulted in a productivity of 6.38±6.06 tons/ha/year for those who exclusively used it, which was significantly higher than the productivity of those using single ingredients or a combination thereof. Interestingly, farmers who solely employed single ingredients and fertilization methods achieved higher productivity than those who combined commercial feed with fertilization (Mwango *et al*., 2016).

The growth rate, productivity, and overall health of animals, as well as the profitability of farms, are directly influenced by the feed they receive. The selection of appropriate feeds and feeding methods is a critical aspect of promoting fish growth (ISU, 2014).

Maulu *et al*. (2019) highlight that in most Zambian aquaculture production systems, feed is distributed evenly across the water's surface through broadcasting or hand feeding. In order to familiarize the fish with specific feeding areas, some farmers concentrate their feeding at particular points within the pond. To prevent feed from drifting away to pond margins, where it becomes difficult for fish to consume and accessible to birds, floating (feeding) hose rings or pipes are utilized as containment mechanisms for floating feeds (Maulu *et al*., 2019).

Feeding trays are used when sinking feeds are used to prevent the feed from sinking directly to the bottom of the pond (Mwema *et al*., 2021). Large-scale commercial fish production is expected to continue expanding, leading to the potential adoption of automatic feeders and other advanced technologies in the future (Maulu *et al*., 2019).

The limitations and potential advancements in the use of commercial feeds.

Restrictions on the use of commercial feeds.

The Zambian aquaculture sector, despite its positive impact on local community development and economic growth, is grappling with several challenges.

1. Zambia's aquaculture industry, as envisioned in Vision 2030 and National Development Plans, could drive economic growth and poverty reduction, but has not fully utilized its potential.
2. Zambia faces significant challenges in local aquatic feed supply, especially for SMEs due to high costs and imports, resulting in quality sacrifices and long travel distances for farmers.
3. Zambia, Africa's sixth-largest aquaculture producer, faces challenges like inefficient and affordable aquafeed, hindering its potential growth and productivity.
4. The Zambian aquaculture sector faces challenges in procuring micro-ingredients like premixes and vitamins, which are mainly imported from South Africa and Zimbabwe, while salt and limestone flour are produced locally.
5. High raw material costs in aquafeed manufacturing can hinder market share expansion, potentially reducing sales due to direct impact on product prices.
6. Rising commercial fish feed costs are causing smallholder farmers to seek alternative feed options like maize bran and plants to meet their fish's dietary needs.
7. Zambia's Livestock Services Co-op Society imports premixes for fish feed production, but high consumption and direct sales to farmers and manufacturers make meeting demand challenging.
8. High import charges on aquaculture inputs in Zambia exacerbate challenges, increasing production costs and making it less economically viable for farmers to engage in fish feed production.
9. The sector faces challenges due to a lack of quality local raw materials, causing farmers to rely on imported ingredients, increasing costs and reducing competitiveness.
10. Zambia's aquaculture sector faces high raw material prices, affecting farmers' ability to afford inputs, affecting productivity and profitability, leading to increased costs and reduced competitiveness.
11. The aquaculture industry's performance is hindered by a shortage of laboratory facilities for wet chemistry analysis, limiting farmers' ability to accurately assess fish feed nutritional content.
12. Many tilapia farmers face financial constraints in acquiring necessary equipment for feeding or harvesting, hindering their ability to improve their farming operations.
13. Aquaculture small-scale farmers face credit and financial challenges, necessitating the development of Marching Grants Facilities (MGF) programs to empower them and ensure their future success.
14. The inadequate infrastructure and technology in fish farming are evident in the inadequate construction of ponds and inadequate water management systems.
15. Farmers, especially in agriculture, often lack the necessary technical expertise and proficiency in crucial areas like fish health management and feed formulation.
16. The Ministry of Livestock and Fisheries must collaborate with various stakeholders to effectively implement aquaculture strategies and interventions, enhancing production and productivity.
17. Fish farmers are facing limited market opportunities due to insufficient market linkages and a lack of integration in the value chain.
18. Environmental issues like water pollution and climate change significantly affect fish production and sustainability.
19. The aquaculture sector suffers from a lack of innovative breakthroughs and refined methodologies due to inadequate funding for research and development.
20. Insufficient assistance and limited extension services hinder small-scale farmers' productivity. A transformation in aquaculture development, led by the Ministry of Fisheries and Livestock, is needed.
21. The aquaculture industry's growth and expansion are hindered by insufficient financial investment and limited private sector involvement.

Potential advancements in the use of commercial aquafeed

The aquaculture sub-sector offers Zambia a chance to tap into the high demand for fish and fishery products in the country and the surrounding regions. With vast potential for investment in feed production, seed production, and aquaculture processing equipment and technology, Zambia can benefit greatly from this opportunity, according to MCTI's 2020 findings.

Status of Aquafeed Production

A Comprehensive Analysis of the Manufacturing Process of Commercial Aquafeed

Zambia's aquaculture growth has significantly transformed the commercial aquafeed sector (Agboola *et al*., 2019), enhancing efficiency and profitability for fish farmers (James, 2018; Musuka, 2021; Mwema *et al*., 2021).

International feed mills in Siavonga district utilize Lake Kariba fish farms for aquatic feed production, contrasting with millers in Lusaka and Copperbelt Province. Mwema et al. (2021) highlight

that they also produce pelleted feed for aquaculture within the country. The transformation of the fish farming industry has been facilitated by favourable conditions, advanced production technology, improved profitability, increased availability of raw materials, agricultural diversification initiatives, and increased fish farmer adoption (Musuka, 2021).

In order to meet the expected growth in aquaculture production, leading commercial operators have established partnerships with feed mills to ensure a steady supply of high-quality feeds at competitive prices, as highlighted by Genschick *et al*. (2017). However, determining the exact market shares of these major players is challenging due to the presence of numerous independent small-scale producers who also source their fish feed from other millers involved in the industry, as reported by CCPC (2019).

The current state of fish feed Production in Zambia

Zambian feed mills invested in aquatic feed development between 2012 and mid-2015 to meet increasing demand in the animal feed industry (Genschick et al., 2017; Ncube *et al*., 2017; Agboola *et al*., 2019; Mwema *et al*., 2021). In 2017, eight fish feed mills were established, and prominent fish feed manufacturers in the SADC region, including Savanna Streams, Farm Feeds, Olympic Milling, Tiger Feeds, Novatek Animal Feeds, Skretting, and Aller Aqua, invested in aquafeed improvement (Mwema *et al*., 2021).

Skrettings and Aller-Aqua are the leading players in fish feed production, with Skrettings boasting a capacity of 100,000 metric tonnes and Aller-Aqua surpassing it at 150,000 metric tonnes.

3.4.1.1.1	Skretting: In Siavonga, Zambia, Skretting Africa and African Century Foods collaborated to establish a fish feed plant with a capacity of 35,000 tonnes. This facility primarily serves Lake Harvest and has aspirations to extend its operations to South-East Africa.
3.4.1.1.2	Aller Aqua: Formed through the collaboration of Aller Aqua Group A/S and Oakfield Holdings Limited, inaugurated a state-of-the-art fish feed plant in Siavonga, Southern Province. With an impressive production capacity of 50,000 tons per year, this factory stands out for its elevated protein content and is widely regarded as the most advanced facility in Southern Africa. Through a strategic partnership with Yalelo Limited, Aller Aqua aims to provide high-quality feed, aiming to alleviate Zambia's annual fish deficit and enhance sales in both Zambia and the neighbouring countries.

Despite having the ability to produce twice the quantity, Aller Aqua and Skretting are presently operating at a reduced capacity of 50-100 tonnes of feed daily. This highlights the requirement for increased capacity and enhanced feed quality (Howell, 2020).

The 2019 report published by CCPC discloses that fish feed millers primarily serve the fish feed market. A significant portion of their production, accounting for 60%, is exported to SADC countries, while the remaining 40% is utilized within the domestic market. The report also emphasizes the financial burden faced by small-scale producers, attributed to the importation of major fish feed ingredients.

Plate 1: *Commercial feeds are available for various species and life stages, and Zambia is now a net exporter of fish feeds.*

Novatek

Novatek, a renowned animal feed company in Zambia, operates two certified feed plants in Lusaka and Mpongwe Farm. These plants have a monthly capacity of 14,000 and 11,000 metric tons respectively and hold ISO 220002 certification (Samboko et al., 2017). Notably, Novatek specializes in the production of extruded fish feed, boasting a monthly production capacity ranging from 1000 to 1200 tons. This impressive range is made possible through the utilization of four distinct product lines: fry mash, juvenile crumble, starter pellets, and grower pellets. Prior to 2015, none of these product lines were available in the Zambian market (Mwema et al., 2021). The company's feed formulation primarily relies on soy-based ingredients, imported fishmeal, and bone meal. Through this process, Novatek successfully creates slow-sinking pellets renowned for their crude protein content, which falls between 18% and 45%. Recognized as a reliable feed supplier, Novatek has successfully expanded its market presence to various regions, including Malawi, Botswana, Zimbabwe, Mozambique, Angola, and Congo. Notably, the company remains focused on supplying directly to commercial farms (Mwema et al., 2021, Musuka, 2021).

Manufacturer	Potential Feed Production (Tonnes)	Actual Feed Production (Tonnes)
Novatek	25,000	25,000
Skretting	50,000	35,000
Aller Aqua		50,000

Source: Musuka, (2021)

Table 1: *The tonnage of aquafeed produced by Novatek, Skretting Zambia, and Aller Aqua.*

National Milling Corporation (NMC).

Zambia's National Milling Corporation, a reliable aquafeed manufacturer, is enhancing its operations by establishing a new facility in Chilanga (Ncube et al., 2017) and implementing advanced mechanization and efficiency measures (Sutton and Langmead, 2013). Through its collaboration with Skretting, they provide a diverse range of fish feeds tailored to various growth stages.

1. **Fry booster** (Feed for newly hatched fry) - This type of feed is intended for the immediate nourishment of fry after hatching.
2. **Fish starter** (Transitional feed for fish) - During the transformation stage from fry to fingerling, fish are given this type of feed.
3. **Fish grower** (Feed for fish growth) - From the fingerling stage to adulthood, this type of feed is used to promote fish growth.
4. **Green Pond** (Final feed for pond organisms) - Prior to being sold in the market, pond finisher is used to maintain the organism's body (Anony, 2011).

Tiger Animal Feeds

Tiger Animal Feeds, a company under the umbrella of Meadow Feeds in South Africa, holds the exclusive rights to produce aquafeeds in Zambia. It is worth noting that Rainbow of South Africa has a 49% ownership stake in this company (Samboko et al., 2017). Furthermore, Meadow Feeds has played a significant role in feed production.

Tiger Animal Feeds was the largest feed producer at the time, producing aquafeed, designed to meet fish development needs at all stages. Their product portfolio encompassed mash, crumbled pellets, and floating pellets suitable for both cages and ponds (Miles and Jacob, 2003; Bentley and Bentley 2005; Anony (2011).

With an annual production capacity of 48,000 tonnes, Tiger Animal Feeds is a prominent exporter of aquafeed, ships out 400 tonnes of aquafeed to Zimbabwe on a monthly basis. In addition to its international endeavours, the company also serves the local market by supplying 100 tonnes of aquafeed, with a special allocation of 2 tonnes for small-scale farmers. As the demand for fish feed among Zambian farmers continues to rise, the company is actively seeking opportunities to expand its export volume to other African countries (Musuka, 2021).

As part of its product range, Tiger Animal Feeds offers 50kg fish feeds, catering to the specific requirements of its clientele.

1. **Fry meal:** The first variant is the Fry meal, which is specifically designed for newly hatched fish fry. This feed contains a high protein content of up to 40%, aiming to promote rapid initial growth and facilitate the transition into fingerlings.
2. **Fish grower meal:** This is intended for fingerlings. This feed maintains a moderate protein level of approximately 35%, providing the necessary nutrients for their continued growth and development.
3. **Green Pond:** A feed exclusively formulated for adult fish. With a crude protein percentage of around 27%, this feed primarily focuses on supporting the maintenance and overall well-being of the fish's body.

Farm feed Limited

Farm feed Ltd, established in 1998, serves the Zambian agricultural industry with integrity. Employing 130 people in Lusaka and Mkushi, they initially provided consulting services but later focused on producing Macro Packs for cost-effective, high-performing feeds.

Farm feed Ltd, a company that produces feed for over 13 species, has relocated multiple times and is currently constructing a new property in Lusaka, ensuring the availability of raw materials.

Table 2 provides a detailed overview of fish feed producers in the country, including feed type, size, form, crude protein and fibre composition, quantity, and farmers' prices during the first and second quarters of 2023.

Name of Fish Feed Producer	Type of Feed Product	Size	Form	Cp/Cf	Bag Size/ Quantiy (Kg)	Price (Zmw)
Farm Feeds Limited						
	Tilapia 42.5/5 Fry Meal fine				50	700
	Tilapia 42.5/35 Starter				25	335
	Fish Grower 28				50	505
	Fish Grower 32				50	535
	Fish Finisher 25				50	465
	Green Pond				50	339
						645
	Aller Aqua					
	Aller Aqua Parvo Gr0	00-0.5mm	Granulate	44/9	25	701
	Aller Aqua Parvo Gr1	0.5-1.0mm	Granulate	44/9	25	701
	Aller Aqua Parvo Gr2	1.0-1.5mm	Granulate	44/9	25	701
	Aller Aqua Parvo Gr3	1.5-2.0mm	Granulate	44/9	25	701
	Aller Aqua Til-Pro	2.0mm	Pellet	40/7	25	660
	Aller Aqua Til-Pro Broodstock	5.0mm	Pellet	34/4	25	560
	Aller Aqua Til-Pro Cage	3.0mm	Pellet	36/5	25	601
	Aller AquaTil-Pro Cage	4.0mm	Pellet	34/4	25	560
	Aller AquaTil-Pro Pond	3.0mm	Pellet	33/5	25	537
	Aller AquaTil-Pro Pond	4.0mm	Pellet	30/5...	25	523
Skretting/Namfeeds						
	Starter					
	Namfeeds Fish Fry		Marsh	48%	10	226
	Namfeeds Fish		Crumble 1	48%	10	226
	Namfeeds Fish		Crumble 2	48%	10	226
	Namfeeds Fish		Crumble 1	48%	25	562
	Namfeeds Fish		Crumble 2	48%	25	562
	Namfeeds Fish		Crumble 3	48%	25	562
	Grower					
	Namfeeds Fish Grower	2.0mm	Pellet	35%	25	396
	Namfeeds Fish Grower	3.0mm	Pellets	32%	25	369
	Namfeeds Fish Grower	4.5mm	Pellets	30%	25	369
	Broodstock					
	Namfeeds fish brood	4.5mm	Pellet	35%	25	432
	Green Pond					
	Namfeeds Pond	2.0mm	Pellet	25%	25	319
	Namfeeds Pond	3.0mm	Pellet	25%	25	317
	Namfeeds Pond	4.0mm	Pellet	25%	25	312
Tiger Animal Feeds						

	Tilapia Fish fry		Mash		25	583
	Tilapia Fish		Crumble		25	567
	Tilapia Fish Grower		Pellet		25	367
	Tilapia Fish		Floating Pellets		25	307
Novatek						
	Tilapia					
	Broodstock				25	393
	Fish Post Hatch	0.2mm	Powder	45%	3	101
	Fish Fry	0.2mm	Mash	45%	15	291
	Juvenile Fish	1.0.2mm	Crumble	45%	15	291
	FishPre-starter	2-3mm	Pellets	40%	25	422
	Fish starter	4mm	Pellets	38%	25	393
	Fish Grower	5mm	Pellets	32%	25	352
	Fish Finisher	5mm	Pellets	24%	25	340
	Pond Fish	5mm	Pellets	18%	25	185
	Fish Green Pond	5mm	Pellets		25	159
	Catfish					
	Catfish weaner			48%	15	341
	Catfish starter			42%	15	547
	Catfish Hatchery				15	409
	Catfish Pre-Grower			36%	25	463
	Catfish Grower			32%	25	427

Table 2: *Selected Commercial Manufacturers Engaged in the Production of Aquafeed in Zambia.*

NMC, a prominent player in the animal feed manufacturing industry, has recently bolstered its production capacity in Chilanga, demonstrating its dedication to meeting the rising demand. In a similar vein, Novatek has established a state-of-the-art plant in the Mpongwe district, specifically catering to the Zamhatch breeding facility, with an impressive monthly capacity of 10,000 tonnes. Meanwhile, start-ups like Emman Farming Enterprises and Pembe Milling have strategically positioned themselves in the Copperbelt areas, allowing them to gain significant advantages (Mwema et al., 2021). Creative investors recognize commercial aquaculture's growth potential (Musuka, 2021).

On-farm aquafeed

Fish feed production on farms can be done in two ways - either by utilizing local resources or by purchasing commercial aquafeed, depending on the financial capacity and size of the farm. This was revealed in studies conducted by Michael (1998) and Bentley and Bentley (2005), as well as Genschick et al. (2017) and Agboola et al. (2019).

Formulation of Aquafeed

Achieving optimal production, meeting consumer preferences, and maximizing net benefits in fish farming heavily relies on the formulation of the feed. This entails carefully selecting the ingredients, ensuring a balanced nutritional profile, and effectively combining the components. However, the process of feed mixing presents its own set of challenges due to various factors that need to be taken into consideration (Firew Admasu, 2021).

The nutritional value of feed is influenced by the species and life stage of farmed fish (Craig, 2019), with tilapia, particularly Oreochromis spp, being the most commonly cultivated in Zambian aquaculture (Kanyembo, 2023).

El Sayed and Indigo Africa notes that Nutritionists in developing countries face challenges in developing commercially cost-effective tilapia feed using local, inexpensive resources, considering factors like genetics, feed intake, nutrient balance, and environmental factors. Eze (2016) emphasizes the importance of considering factors like nutritional requirements, ingredient values, physiology, chemistry, availability, palatability cost, processing technology, and dietary components when selecting fish feed formulas and ingredients for optimal growth of fish. Certain ingredients like binders and antioxidants may be added for physiological or economic reasons.

To improve aquafeed nutritional value, use locally available feedstuff and cost-effective methods, focusing on digestibility, eliminating antinutritional factors, and enhancing palatability (Ogugua and Eyo, 2007). No single feed ingredient can provide all the necessary nutrients for optimal fish growth, hence, local ingredients like fish meal, soybean meal, rice bran, snail meal, and mixed vitamins are preferred to minimize costs (Aizam et al., 2018).

In their study, Fregen et al. (2020) underscore the positive aspects of artificial feeds for farmers, such as higher stocking density, faster growth, guaranteed yield, biodegradability of uneaten feed acting as a fertilizer to promote plankton growth, and the ability to monitor fish health during feeding.

Feed ingredients

The optimal proportions of feed ingredients for fish growth depend on factors like nutrient requirements, availability, cost, and processing characteristics, with no single ingredient providing all necessary nutrients.

Standard fish feed formulations include fish meal, blood meal, poultry meal, and feather meal, often combined with plant-based protein feedstuffs like soybean meal, groundnut cake, cottonseed meal, and sunflower seed meal. Plant-based sources are readily available and serve as a complementary source to animal protein sources, as noted by Agboola et al., 2017.

Soya bean meal is replacing fish meal due to its high fat content, necessitating supplementation with fish meal and wheat offal.

Gossypol, a substance found in cottonseed meal, can have adverse effects on fish. However, poultry by-product meals, which consist of waste materials from poultry processing, can be safely utilized as a source of fish feed without any harm to the fish (CCPC, 2019).

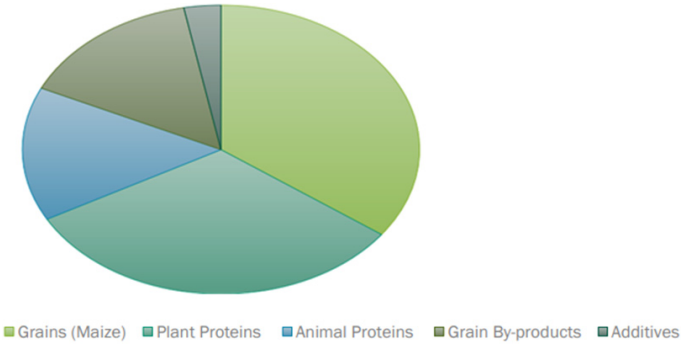

Figure 3: *Fish Feed Raw Material Breakdown.*

Ingredient	Research action(s) needed Protein sources
Fishmeal	• The majority is sourced from neighbouring 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.
Cottonseed 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 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 proteins present in brewers' dried grain.
Feather meal	• Improve collection and processing methods to increase the availability of feather meal for aquafeeds.

Blood meal	• Improve collection and processing methods to increase the availability of blood meal for aquafeeds.
Beef and pork meal	• Further information needed on the availability within the country.
Poultry meal	• Organize logistics around the 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 fibre 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

Adapted from Agboola *et al*., (2017).

Table 3: *Priority ingredients to be considered for aquafeed, with proposed further research to improve their nutritional quality.*

According to CCPC (2019), soya beans make up the majority of Zambia's fish feed at 55%, while maize usage stands at 40%. As maize is mainly used for energy, protein sources such as fish meal, soybean meal, rice bran, and mixed vitamins are utilized to keep costs manageable (Aizam *et al*., 2018).

Fregene *et al*., (2020) emphasize the importance of considering specific conditions when selecting feed ingredients to ensure the production of high-quality feed.

1. **Cost:** Feed costs in fish farming account for 70% of production costs, making it crucial to consider materials and ingredients used and find cost-effective solutions without compromising quality.
2. **Age of fish:** The nutritional requirements of fish are determined by their life stage, making it crucial to provide the appropriate nutrients based on their age.
3. **Species:** Fish species exhibit varying feeding behaviours, with some being carnivores and others herbivores, which significantly impacts their acceptance of specific types of feed or food.
4. **Nutritional composition:** The nutritional composition of feed ingredients, including crude protein, carbohydrates, fat, vitamins, minerals, and gross energy, is crucial for understanding the proportion of nutrients present.

Ingredient digestibility

Digestibility is a crucial factor that influences an animal's ability to absorb energy and nutrients from a feed ingredient through digestion and absorption. The selection of feed ingredients for feed mills is influenced by factors like protein, fat, carbohydrate digestibility, buoyancy characteristics, cost, and availability (ISU, 2014).

Factors that Influence Feed Digestibility

Digestibility in fish feed is primarily influenced by the chemical composition of the feed ingredient and the characteristics of the cultured fish. The query should be addressed considering the following factors:

1. **Fish Species under culture:** The specific fish species being cultured can significantly influence their nutritional needs and digestion capabilities.
2. **Physiological condition of the feed:** Stress or disease in fish can affect their hormonal profiles, affecting the secretion of enzymes involved in digestion.
3. **Age and Size:** Fish age and size affect their nutrient digestion, with younger fish preferring easily digestible live food, and larger fish having longer intestinal lengths causing increased digestion and assimilation time (Nguyen, 2010; Ginindza, 2012).
4. **Temperature:** Water temperature significantly influences fish's metabolic rate, health, nutrition, feeding behaviour, and overall well-being, influencing their overall health and overall well-being.

5. **Feed ingredient quality and quantity:** The quality and quantity of ingredients in fish feed formulation significantly influence nutrient utilization, with amino acid composition notably affecting the overall quality of dietary protein.
6. **Feeding frequency ratio:** Feed frequency ratio significantly impacts fish intake, growth, and water quality. Low FCR indicates efficient utilization and absorption, minimizing waste (Ginindza, 2012).

Raw Materials

Aquafeed ingredients made from agro-industrial by-products like beef, pork meal, sugar cane pulp, potato peels, tomato waste, and coffee by-products are feasible but limited due to resource scarcity (Agboola *et al*., 2017).

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.

Table 4: *Crop production in Zambia (2016).*

Quality Control and Assurance

Aquatic feed manufacturers must inspect suppliers' facilities, assess standards, obtain certificates of analyses, review data, verify reliability, request insurance certificates, and obtain ingredient samples. They must select raw materials from reputable sellers for safe, wholesome ingredients which are crucial for the feed's nutrient source (Musuka, 2021).

Essential Nutrients for Aquafeed Formulation

The significance of carefully considering multiple factors in the selection of a feed formula for fish growth is emphasized by Eze (2016). These factors include the nutritional requirements of the fish, the nutritional values of the ingredients, the physiological aspects of the fish, the chemistry of nutrients, the functions of metabolism, the availability and palatability of the feed, the cost implications, the processing technology utilized, and the incorporation of dietary components such as binders and antioxidants.

The formulation of fish feed plays a crucial role in ensuring that fish receive the necessary nutrients during their growth stages. This process takes into account factors such as feeding habits, physiological stages, and environmental variables. The goal is to create a feed that is both cost-effective and nutritionally adequate, which requires precise ingredient ratios. Studies conducted by Ghosh et al. (2011) and Singh (2020) emphasize the importance of accurately formulating fish feed. Furthermore, it is important to note that the nutrient demands of organisms can vary depending on their life cycle stages and may be influenced by the specific production systems and species utilized.

Energy and Protein Supplements

Fish culture categorizes feedstuffs into two main groups: energy feedstuffs and protein supplements.

1. **Energy feedstuffs:** Energy feedstuffs, such as maize meal, wheat meal, rice bran, and cassava peel, are utilized in aquafeeds for fish. These products have a crude protein content of less than 20%. It is worth noting that freshwater fish tend to digest and utilize carbohydrates more than cold-water and marine fish. This distinction is supported by studies conducted by Agboola et al. (2017) and Aizama et al. (2018).
2. **Protein Supplements:** Feedstuffs referred to as protein supplements are feed materials that have a crude protein content of 20% or more. These supplements are sourced from both plant and animal origins and are classified as feedstuffs. Animal proteins, such as fishmeal, meat meal, bone meal, and blood meal, are considered to be of superior quality and offer greater nutritional value in comparison to plant-based proteins. Additionally, plant protein materials like soybean meal, groundnut cake, and cottonseed cake are used as protein supplements in fish culture (El-Sayed; Fregene et al., 2020).

Protein

To support their maintenance and growth, animals, including fish, need protein (Robinson and Li, 2015). Fish, in particular, require two to three times more protein than other animals (Ogugua and Eyo, 2007; Aizama *et al*., 2018). To avoid any complications, it is crucial to provide them with the appropriate amount of protein (Aizama *et al*., 2018).

Protein plays a crucial role in various bodily functions such as muscle formation, blood formation, tissue formation, hormone and enzyme production, as well as energy production (Ogugua and Eyo, 2007; Aizama *et al*., 2018). It is important to maintain a sufficient protein intake to prevent protein loss in fish tissues and minimize water pollution. However, excessive consumption can result in protein loss through the kidneys and gills, while inadequate consumption can also lead to protein loss (Aizama *et al*., 2018).

Fishmeal is a valuable protein source that is extensively used in aquaculture due to its well-balanced amino acid profile, which includes Lysine, Methionine, and Tryptophan. These nutrients are often deficient in plant-based sources, making fishmeal an excellent choice for fish feed (El-Sayed, 2004).

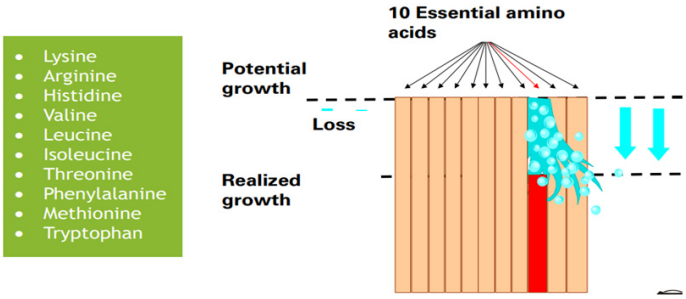

Figure 4: *Nutrient Requirements -Protein.*

The European Market Observatory for Fisheries and Aquaculture Products (2019) revealed that the global production of fishmeal in 2018 reached its highest level since 2011, amounting to an estimated 5.6 million tonnes. The intensification of fish production from aquaculture has made its demand for fishmeal from small pelagic fishes as an increasingly important issue. Fishmeal finds its primary application in aquaculture feed, as well as in the diets of poultry and pigs. The intensification of fish production from aquaculture has made its demand for fishmeal from small pelagic fishes as an increasingly important issue (Soliman et al, 2017). In terms of consumption, the aquaculture sector dominates, accounting for approximately 70% of global fishmeal and fish oil consumption in 2017. During the same year, pig feed utilized 22% of the fishmeal, while poultry feed accounted for 5%. In 2016, crustaceans consumed 31% of the fishmeal intended for aquaculture, followed by salmon and trout at 23%, and other marine fish at 15%.

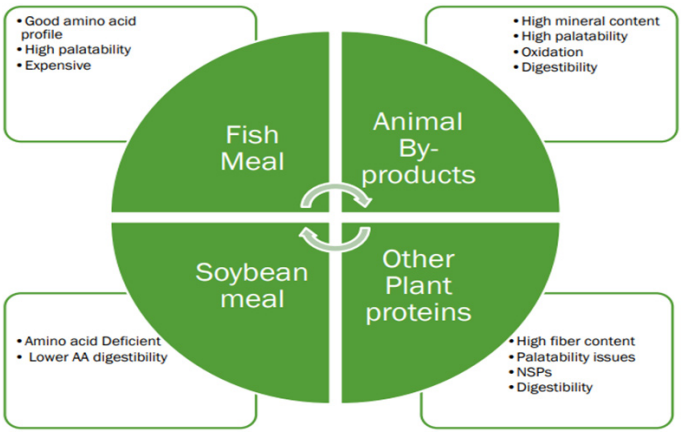

Figure 5: *Protein content.*

Potentials for fishmeal replacements in aquafeeds

In light of the scarcity of fishmeal and the rising demand for livestock and poultry feeds, there is an urgent requirement for more affordable protein alternatives that can be obtained locally (Yueming Dersjant-Li, 2002). By substituting fishmeal and fish oil with nutritionally equivalent feed ingredients in aquafeeds, the aquaculture industry can decrease its reliance on wild fish stocks and mitigate the cost of feed inputs (Soliman *et al*., 2017).

Various efforts have been undertaken to substitute fishmeal with plant protein sources like soybean meal, groundnut cake, cottonseed cake, animal and fishery by-products, as well as novel foods in aquaculture feeds (Soliman et al., 2017).

The protein requirements of tilapia are influenced by various factors such as fish size or age, dietary protein source, energy content, water quality, and culture conditions (El-Sayed).

Protein needs of fish vary based on factors such as rearing environment, water temperature, quality, genetic composition, and feeding rates, with smaller fish requiring higher protein levels (Craig, 2019). According to Aizama et al. (2018), catfish necessitate a protein intake ranging from 25% to 40% for their growth to reach optimal levels. Ensuring their well-being requires the provision of feeds with a substantial crude protein content, ideally between

35% and 50%. Remarkably, even commercial feeds containing as little as 24% protein can still promote rapid growth in these aquatic creatures.

Life stage Weight (g)	Requirement (%)	First feeding
Larvae	-	45-50
Fry	0.02-1	40
Fingerlings	1-10	35-40
Juveniles	10-25	30-35
Adults	25-200	30-32
Adults	>200	28-30
Broodstock	-	40-45

Source: https://www.fao.org/fishery/affris/species-profiles/nile-tilapia/nutritional- requirements/en/

Table 5: *Protein Requirement of Tilapia across Stages in Freshwater.*

Nutrient Recommended	Comment
Protein (%)	
26-32	Grow-out
32–35	Fingerlings
40-50	Fry

Source: Robinson and Li, 2015.

Table 6: *Nutrients recommended for catfish feeds.*

S/No	Common Name	Fish	% crude protein requirement
1.	Tilapia	Oreochromis niloticus	
		Larvae/Fry	35-50
		Juvenile	30-40
		Adults	20-30
		Broodstock	35-45
2.	African catfish	Clarias gariepinus	
		Fry	50
		Fingerlings	40
		Juveniles and adults	35

Adapted from: Fregene et al., 2020

Table 7: *Protein Requirements of Tilapia and African Catfish.*

Nutrients Recommended for Catfish Grow-out Feeds

Nutrient	Recommended level[a]	Comments
Protein (%)	26–32	Varies, depending on fish size, water temperature, dietary energy level, and daily feed allowance.
Essential amino acids (% of protein):		
Arginine	4.3	Generally, if lysine and sulfur-containing amino acid requirements are met, other amino acids will be adequate with feedstuffs commonly used in catfish feeds. Cystine can replace about 60 percent of methionine requirement. Tyrosine can replace about 50 percent of phenylalanine requirement. Synthetic amino acids can be used to supplement deficient proteins.
Histidine	1.5	
Isoleucine	2.6	
Leucine	3.5	
Lysine	5.1	
Methionine	2.3	
Phenylalanine	5.0	
Threonine	2.0	
Tryptophan	0.5	
Valine	3.0	
Digestible energy (kcal/g protein)	8.5–9.5	Use carbohydrate and lipid (fats or oils) as energy to save protein for growth.
Lipid (%)	4–6	May use a mixture of animal, vegetable, and fish oils. High levels of marine fish oil may give a "fishy" flavor to the fish. Spray supplemental fat or oil on pellet surface.
Carbohydrate (%)	25–35	Floating feeds require at least 25 percent grain. Use grain by-products for good expansion and bonding. Keep crude fiber below 7 percent.
Vitamins:		
A	1,000 IU/lb	Acetate ester is used to improve stability during feed processing.
D_3	500 IU/lb	D-activated animal sterol is used as source of D3.
E	30 ppm	DL-tocopheryl acetate is used for improved stability.
K	4.4 ppm	Required, but level for catfish not known. Menadione sodium bisulfite is used to ensure adequacy.
Thiamin	2.5 ppm	Thiamin mononitrate is generally used.
Riboflavin	6 ppm	
Pyridoxine	5 ppm	Pyridoxine HCl is generally used.
Pantothenic acid	15 ppm	Calcium d-pantothenate generally used.
Nicotinic acid	None	Required, but feed contains enough nicotinic acid without adding a supplement.
Biotin	None	Required, but feed contains enough biotin without adding a supplement.
Folic acid	2.2 ppm	

Source: Mississippi State University, 2006: Robinson and Li, 2015

Table 8: *Nutrients recommended for catfish Grow-out feeds.*

Protein quantity, particularly crude protein, is the primary factor that affects the price of feed preparation. It is crucial to maintain a balance between digestive protein and amino acids. Additionally, essential nutrients like water, fat, and carbohydrates play a significant role in feed preparation, as emphasized by Singh (2020).

Energy (Carbohydrates)

Freshwater fish, in particular, depend on carbohydrates as their primary source of energy due to their low crude protein content, which is usually less than 20% (Aizama et al., 2018). These omnivorous species obtain 25% to 40% of their soluble carbohydrates from various plant sources such as maize, guinea corn, millet, cassava, and rice bran, as reported by Ogugua and Eyo (2007). The authors found that artificial feed containing carbohydrates has a protein-sparing effect, enabling fish to efficiently use proteins for growth rather than energy (Ogugua and Eyo (2007).

Vitamins and minerals

This category of nutrients plays a crucial role in the body's development, well-being, and functioning.

Vitamin

Adequate vitamin intake plays a critical role in promoting the health and growth of fish by strengthening their immune system and preventing stunted development. Furthermore, vitamins act as an attractive element in fish feed, stimulating the fish to consume it. Fish are particularly susceptible to bacterial activity, emphasizing

the importance of vitamins in strengthening their immune system. To prevent hindered growth, it is vital for fish feed to contain essential vitamins such as Vitamin C and B-complex, which enhance immunity and the ability to combat stress (Aizama et al., 2018; Singh, 2020).

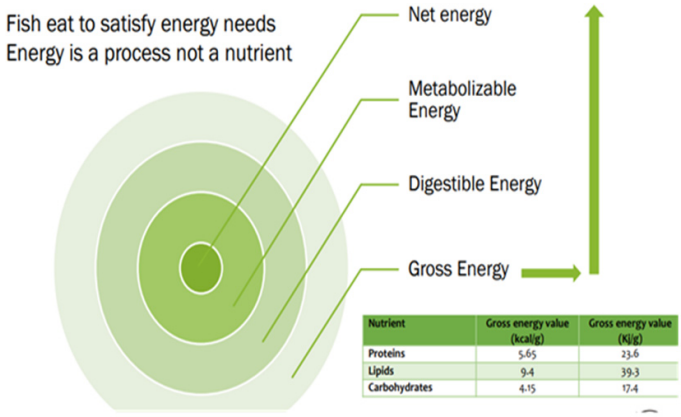

Figure 6: *Nutrient Requirements-Energy.*

Minerals

Minerals are crucial for fish feed preparations, promoting bone development and preventing anaemia and short trunk due to iron deficiency and zinc, manganese, and copper deficiency (Singh, 2020; Fishfeedmachinery.com).

Oil and fat

Lipids, essential nutrients, can serve as a protein substitute in aquaculture feeds, according to Aizama *et al*. (2018).

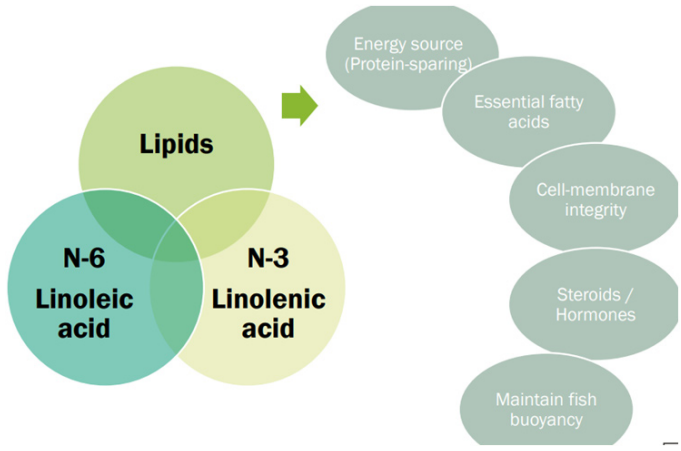

Figure 7: *Nutrient Requirements-Lipids.*

Zambia has various sources of lipids, including fish oil, soybean oil, groundnut oil, sunflower oil, and cottonseed oil.

Crude Lipid (% min)		10-15
Essential fatty acids, % min		
	18:2n-6	0.5-1.0
	20:4n-6	1.0
	18:3n-3	
	20:5n-3	
	22:6n-3	
Carbohydrate, % max		40
Crude fibre, % max		8-10
Protein to energy ratio (mg/kcal)		110
		120

Table 9: *Crude Lipids, Essential Fatty acids and energy.*

Eze (2016) highlights that these fats, rich in essential fatty acids, significantly enhance the energy content of food. Fish digestibility in lipids ranges from 85-95% (NRC, 1993), with increased levels affecting fresh fish quality due to increased lipid storage in edible muscle (Turchini et al., 2009).

Selection of Fish Feed Composition

Ensuring the right composition of fish feed is of utmost importance when it comes to maintaining the health and nutrition of fish. This involves considering factors like nutritional requirements, feed value, palatability, digestibility, protein-amino acid balance, and economic benefits. Different fish species have varying nutritional needs, and it is essential to strike a balance between protein and amino acids for their optimal growth. While reducing material costs is important, it should not compromise the presence of essential nutrients (Zenopelletmachine.com).

To ensure fish receive optimal nutrition, it's crucial to accurately determine the optimal proportions of feed ingredients, considering factors like feeding patterns, physiological stages, and environmental conditions, and calculate these ratios based on these criteria (Ghosh et al., 2011; Singh, 2020).

The selection of ingredients for aquafeed should consider three factors: quantity, quality, and price, ensuring they are available, nutrient-rich, and free from anti-nutrients (Singh, 2020).

Selecting feed ingredients involves considering fish stock's nutritional needs, anti-nutritional or toxic factors, preferred ingredients, and palatability when formulating feed.

- Fish farmers must understand the nutritional value of materials, their fish's growth stages, and avoid anti-nutritional components.
- They must consider availability, price, and palatability of ingredients.
- Using low-cost ingredients can reduce production costs and increase revenues.
- Feed compositions should balance costs and benefits, using low-cost ingredients to reduce production costs and increase revenues.
- Choosing local fish meal or plant-based protein sources like soybean meal or GNC can help cut costs. However, animal protein should not be completely eliminated, especially for African catfish feed, to maintain quality and quantity.

When designing feed, consider available processing technology to ensure nutritional value. Crude processing methods may lead to nutrient loss, while poorly milled ingredients, like maize, may cause digestion issues in fish. Therefore, use only the best technology.

Ingredient	Inclusion level (Kg/ t				
	Fry (To 1mm)	Fingerling (To 3mm)	Juvenile (To 5mm)	Grower (To 8mm)	Brood stock (8 or 9mm)
Fishmeal (72%)	450	400	300	200	350
Soybean meal	230	200	220	240	230
Groundnut cake	150	150	200	250	150
Maize	165	245	275	305	262.5
Additive	5	5	5	5	5
Total	1000	1000	1000	1000	1000
Total CP (%)	50	46	42	38	44
The additive is assumed to have an inclusion level of 5kg/t. Adapted from: Zeno pellet machine.com.					

Table 10: *Fish Feed Formulation for Catfish Growth.*

Tips for enhancing the production of aquafeed

To improve aquafeed production, the following measures should be implemented:

- Improving the information system to ensure the availability, accessibility, and affordability of quality feeds. Moreover, it is essential to provide species-specific feeds that cater to the nutritional requirements of the cultured fish.
- Establishing mini feed mills: Mini feed mills should be established in rural areas to provide high-quality, accessible feed to small-scale fish farmers. Incentives should be given to fish feed suppliers to establish outlets, promoting market size attainment and aquaculture sustainability.
- The training of farmers and stakeholders in feed management, best practices, and profitable techniques is crucial, along with the documentation and dissemination of economically viable technologies.
- Developing fish feed standards ensures quality, increasing productivity and cost savings for farmers. Adopting appropriate feed management strategies is crucial for maximizing returns (Mbonge et al., 2014).
- The Zambia Bureau of Standards (ZABS) has developed a Zambian Standard (DZS 1212 2020) to address compounded fish feeds in aquaculture, specifically focusing on tilapia and catfish feeds. This standard addresses the lack of existing ZABS regulations on fish feed manufacturing.
- The Zambia Aquaculture Enterprise Development Project (ZAEDP) seeks to enhance aquaculture production and productivity in order to improve the livelihoods and living standards of rural households. A key aspect of achieving this goal is the enhancement of aquatic feed quality, which can be achieved through various means, including the implementation of legislation, regulation, standards, and effective enforcement mechanisms (Ng'ambi, 2019).
- In order to address the challenges faced by the aquafeed industry, it is important to focus on promoting research that is demand-driven, participatory, and adaptable. This will help in finding scientifically-based and practical solutions. In Zambia, future research should prioritize the exploration of aquafeed ingredients such as algae, insect meal, and microbial biomass (Agboola et al., 2017). These advancements will contribute to the development of the field. However, it is worth noting that the lack of accessible components like synthetic amino acids lysine and methionine poses challenges to the development of alternative aquaculture feeds in Zambia.

- The development of aquatic feeds utilizing local ingredients is anticipated to boost income, enhance food security, and mitigate pollution.

Conclusion

The feed industry in Zambia is making strides towards offering superior and affordable feeds for fish farming. By promoting the commercial cultivation of soya beans, the sector can effectively lower input expenses and boost competitiveness. It is imperative for fish farmers to receive training on transportation and storage practices, while conducting periodic inspections on the feeds is essential to ensure their quality.

Author statement

The manuscript review and writing idea was set in motion by Confred G. Musuka, who received valuable assistance from co-authors in conducting literature reviews and drafting the manuscript.

Declaration of Competing Interest

The authors claim to have no known financial or personal relationships that could have potentially influenced the work presented in this paper.

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