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INGREDIENT SELECTION FOR AQUACULTURE FEEDS IN MUCHINGA PROVINCE, ZAMBIA

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ABSTRACT

Aquaculture in Africa faces significant challenges, particularly due to the high costs of fish feed, which can represent 40-70% of the total production expenses. The present study aimed to analyze the types of local ingredients available for fish feed production, their regions of production, and their seasonal availability. To collect this data, 200 stakeholders were interviewed across four districts in Muchinga Province: Chinsali, Nakonde, Isoka, and Mpika. A total of 20 different ingredients were ranked based on availability and abundance, with 60% classified as plant-based, 27% as animal sources, and 9% as other types of ingredients. Results indicated that among the plant ingredients, the primary sources included maize (*Zea mays*), which accounted for 27%, followed by sunflower (*Helianthus annuus*) and rice (*Oryza sativa*), each representing 22*%. Other notable plant sources were cassava (Manihot esculenta) at 9%, velvet bean (Mucuna* pruriens) at 17%, cow peas (*Vigna unguiculata*) at 6.2%, and chikanda (*Disa robusta*) at 9%. For animal ingredients, the predominant sources were two types of caterpillars, with the first species (*Gonimbrasia belina*) making up 86% and the second species comprising 14%. Additionally, various by-product ingredients were identified that would be beneficial, including palm seed oil (*Elaeis guineensis*) 20%, sunflower cake 65%, rice bran 11%, soybean cake 4%, chikanda powder 3%, and cassava chips 7%. The study underscored the diversity of local ingredients in Zambia that can be used for creating fish feeds. Additionally, it offered important perspectives on the sourcing and assessment of these ingredients, suggesting that proximate analysis and digestibility studies be carried out to determine their nutritional properties for possible inclusion in fish feed formulations. By employing these strategies, stakeholders can optimize fish feed production, enhance the overall health of aquaculture systems, and contribute to the sustainability of food production in Zambia. As the aquaculture sector continues to grow, leveraging local resources will be important to achieving food security and economic development in the region.

Key words: Aquaculture, Fish feeds, Local raw material, Organic by-products, Zambia

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INTRODUCTION

Aquaculture in Zambia plays a crucial role in enhancing fish production and ensuring food security. However, despite its growth, production remains below national demand [1, 2, 3]. One of the major constraints is the high cost of fish feed [1]. Feed is a critical component in aquaculture, yet the fish feed industry in Zambia remains underdeveloped [4, 5, 6]. The sustainability of aquaculture largely depends on the availability and quality of feed, as it directly influences the growth and survival of fish larvae [6, 7]. High-quality feed is essential for maximizing fish growth, improving feed utilization efficiency, and enhancing flesh quality [8]. Notably, fish feed accounts for approximately 65 to 70% of the variable costs in fish farming [9, 10]. All living organisms feed to maintain their normal body physiology and growth. This growth may be seen as an increase in the number of cells and invariably body length and weight. Fish feed may be grouped into three forms: (i) natural live foods, (ii) conventional raw materials and (iii) non-conventional raw materials. Natural live food occurs naturally in the environment where the fish live such as planktons or other natural food materials [2, 3]. According to Madu *et al.* [12] non-conventional raw materials are usually rare in markets and not commonly used in producing fish feed commercially. Whilst, conventional raw materials are commonly known and widely accepted for use as fish feed [5, 6]. Irrespective of the classes of raw materials fish feed contains, supplying the target organisms with a balanced diet is important to promote bodybuilding and high yields, particularly under intensive fish culture systems where all nutrients are supplied in complete feeds [8, 13, 14].

The success of fish yields is influenced by the composition and digestibility of feed ingredients, making the formulation of adequate feed combinations essential for enhancing digestibility and utilization [1]. In Zambia, the rising costs of formulated fish feeds, largely driven by reliance on imported ingredients, are a significant challenge to the growth of the aquaculture sector [1, 6]. Therefore, there is a pressing need to investigate both conventional and non-conventional local raw materials and by-products to identify potential local alternatives for fish feeds. The goal is to develop low-cost, sustainable feeds that optimize nutrient utilization and support the expansion of Zambia's aquaculture industry.

The baseline study on the status of aquaculture feeds and local ingredients was done in districts of Muchinga Province in Zambia. The objective of this screening study was to provide information on the sources, availability and seasonality of the ingredients and fish feeds that are found in Muchinga Province of Zambia.

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METHODOLOGY

Study site

The study was done in 4 districts in Muchinga Provinces of Zambia. Muchinga (Figure 1). The selection of the districts was based on the outcome of a brief consultation conducted with different organisations that include the Ministry of Agriculture, Ministry of Fisheries and Livestock, feed millers, brewery companies and the Indaba Agriculture Policy Research Institute (IAPRI). In addition, the selection criteria of the districts were also based on the high potential for aquaculture, existing high amount of agriculture, livestock and fishery production, and food and beverage processing industrial yards present in these areas. Based on these criteria these districts would theoretically be able to provide inputs for fish feed production [15].

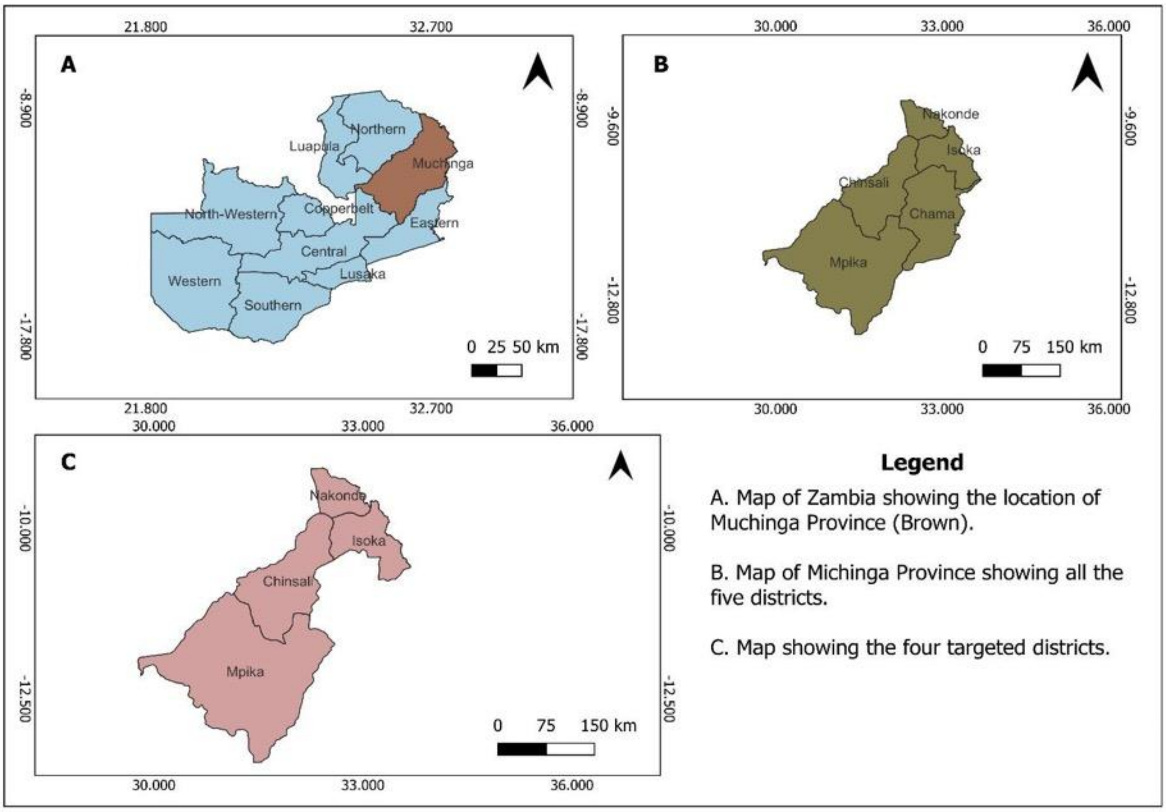

Figure 1: **Map showing the four targeted districts of Muchinga Province**

Sampling design and data collection

This was a cross-sectional study as such a purposive sampling technique was used. This technique is a non-probability sampling in which units are selected on purpose and those that have characteristics that are needed in the targeted sample [17]. The selection of local ingredients and feeds was guided by three criteria: seasonality, abundance over the last 5 years, and quantity available [15]. The

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targeted nutrient source categories included proteins, carbohydrates, lipids, vitamins, and minerals, which were further classified into animal and plant sources. Ranking was used based on the aforementioned categories to select districts and wards where local ingredients and feeds are most located. From 4 targeted districts; Isoka, Chinsali, Mpika, and Nakonde 5 high-performing camps/wards were selected within each district. In these selected areas, interviews were conducted with 5 stakeholder groups: local markets, farmers, grain/feed millers, processing firms, and government/NGO representatives. A total of 200 interviews were completed across the surveyed districts in Muchinga Province.

Semi-structured template/questionnaire was used to collect data through interviewing key informants that include feed millers, farmers, raw material (ingredient) producers, sellers of raw materials, sellers of feeds, government officials, brewery companies and food processors. A total of 200 semi-structured questionnaires were administered. The fish feed ingredient screening exercise lasted for a period of 2 months (August and October 2023). The semi-structured template/questionnaire was designed to capture data on ingredients and fish feeds based on seasonality of the availability and quantity in tones or kilograms equivalent in a particular location.

Data analyses

The information was collected via spreadsheets using Microsoft Excel 2016 (Percentage and Average functions). For the non-parametric data, non-parametric tests (Cross tabulations and Chi-square (χ2)) were used to examine the associations of type of ingredients produced in surveyed districts and wards, and any categorical data (Type of ingredient, seasonality and availability in last 5 years). Fisher's exact test was utilized when the assumptions for the Chi-square test were not met. The Mann–Whitney U test was applied to identify differences among categorical data. For parametric data regarding ingredient production quantities within a district. Paired T-Test was done on heterogeneous subsets, with significance set at $P < 0.05$ for mean differences. Additionally, Principal Component Analysis (PCA) was performed to analyze ingredient type, production location, and pricing. All statistical analyses were carried out using R software version 3.9.0 [18]

RESULTS AND DISCUSSION

This research highlights the diverse array of local feed ingredients available in Muchinga Province, Zambia, and their untapped potential for enhancing commercial fish feed production. Current studies are investigating a range of indigenous resources, including insect-based proteins, plant byproducts, and other alternative feed materials, to develop nutritionally balanced and cost-effective feed

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formulations [19,20,21,22]. Innovative strategies such as the nutritious pond concept leverage underutilized local resources to not only enhance aquaculture productivity but also promote ecological sustainability. This approach aligns with circular economic principles by reducing feed waste and recycling nutrients within aquatic systems [23]. To secure the long-term sustainability of aquaculture in sub-Saharan Africa, it is crucial to intensify research and development efforts focused on optimizing locally available feed ingredients, improving feed conversion efficiency, and scaling up affordable feed production technologies. The study identified 20 assorted feed ingredients mapped across the four districts of the Muchinga Province. The mapping criteria were based on type, seasonality, source and availability in large quantity (> 1 Metric Tons/year). This mapping aligns with [24] and [25] who stated that the use and selection of ingredients in aquaculture depends on accessibility, availability, price and nutrient contents and this knowledge is critical to the advancement of the aquaculture in a sustainable manner especially in Sub-Saharan Africa. The results revealed that plant-based ingredients dominated, accounting for 70.4% (N=13) of the total ingredient sources, whereas animal-based ingredients comprised 22.2% (N=6). Plant ingredient sources, cultivated in surveyed districts, included maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), chikanda (*Disa robusta*), soybean (*Glycine max*), sunflower (*Helianthus annuus*), cowpeas (*Vigna unguiculata*), cassava (*Manihot esculenta*), velvet bean (*Mucuna pruriens*), pumpkin leaves (*Cucurbita pepo*), tea leaves (*Camellia sinensis*), and palm tree seed oil (*Elaeis guineensis*) (Table 1). Animal-based ingredients included two species of caterpillars: *Gonimbrasia belina* and *Gonimbrasia zambesina* (Table 1). Additional by-products, such as soybean cake, sunflower cake, sunflower cake residue, palm tree seed oil, maize bran, and rice bran, were also identified.

Production Trends of Feed Ingredients

In the last 5 years, fluctuations in local feed ingredient production were noted across the surveyed districts. The average yearly output of plant-based components reached 34,600 metric tons, exceeding that of animal-derived ingredients at 19,700 metric tons. Interestingly, areas with less rainfall showed slightly higher and more diverse ingredient production than their wetter districts. However, overall absolute production remained relatively consistent among the districts within each district (Figures 2 and 3).

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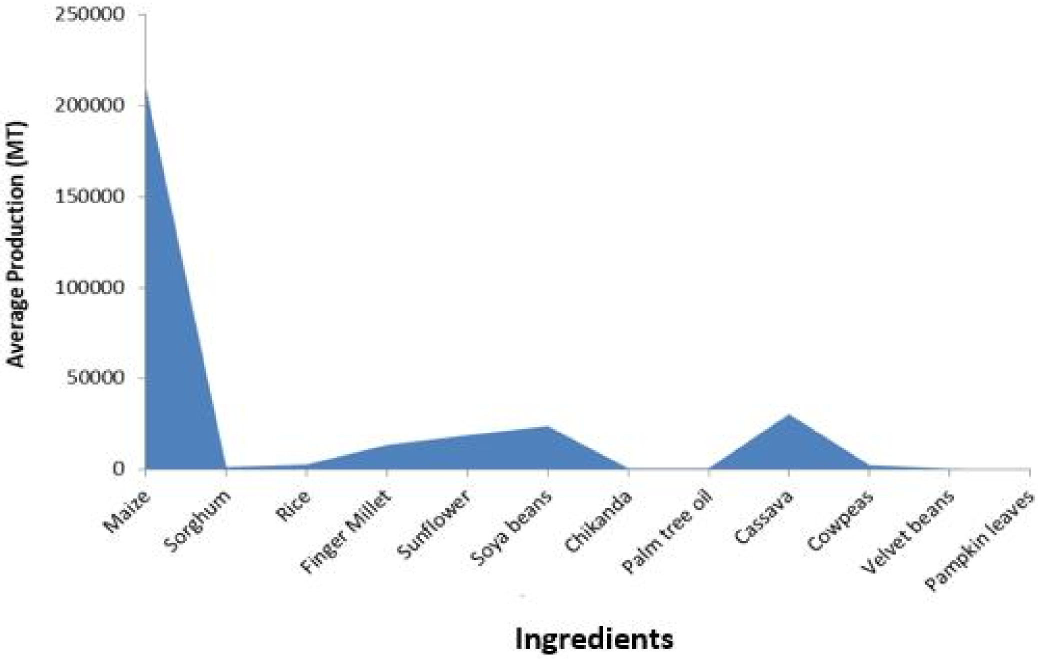

Figure 3: Production (MT) of plant ingredient sources in surveyed districts of the province during the August-October 2023 survey period

Maize has emerged as the leading plant-based feed ingredient, with an average annual yield of 328,900 metric tons. The dominance of maize compared to other commodities is not surprising because, in Zambia, maize is the main crop farmed by majority agriculture farmers and was long established as a critical agriculture crop as early as 1966 [26]. This was followed by soybeans (20,850 metric tons), sunflower (7,441 metric tons), velvet bean (5,842 metric tons), rice (4,506 metric tons), and sorghum (1,226 metric tons) (Figure 3). The observed regional disparities in production were primarily attributed to variations in rainfall patterns and agroecological zones. Principal Component Analysis (PCA) showed that certain ingredients, including finger millet, sorghum, and cowpeas, displayed an average production variation of 71.4% along the first axis. This was significantly different from other major ingredients such as maize, rice, sunflower, and soybeans (65±7, $P < 0.05$), suggesting that climate fluctuations play a substantial role in ingredient production (Figure 4).

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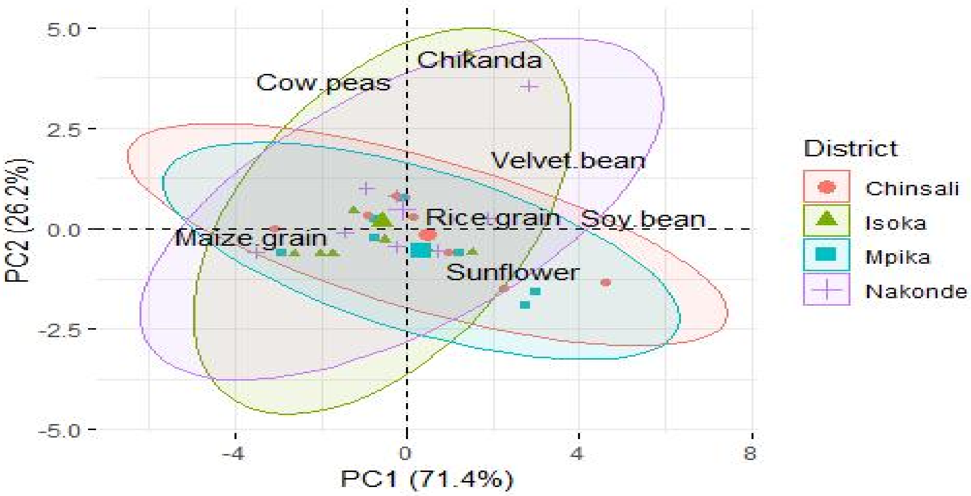

Figure 4: PCA clustering of major plant ingredients based on their type and availability in surveyed districts in Muchinga Province during the August-October 2023 survey

Production of *G. belina* (Caterpillar 1) was highest in Isoka District compared to Mpika and Chinsali Districts, with an average annual production of 8,035±2 metric tons and 2,000±2 metric tons, respectively. The overall production of *G. zambesina* (Caterpillar 2) was significantly lower at 2,629±1 metric tons per year, and it significantly differed ($P<0.05$) from *G. belina* (5,485±1 metric tons) (Table 2). The seasonal availability of animal-based ingredients was more aligned with fish product production than caterpillar harvesting. PCA analysis showed a 57.6% variation along the first axis between the two-caterpillar species (Figure 5).

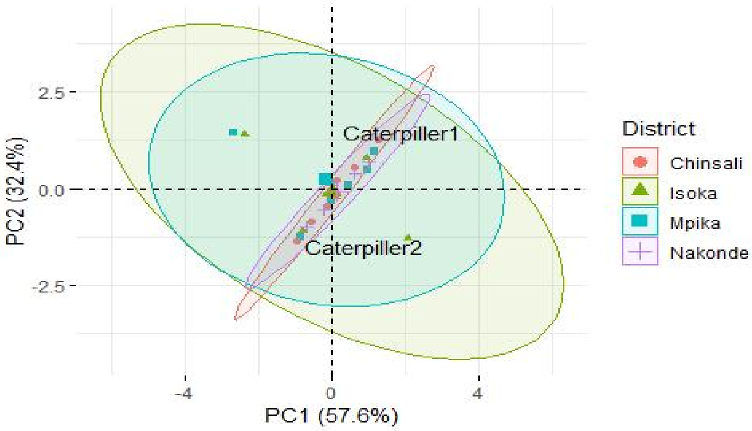

Figure 5: PCA clustering of animal ingredients based on their type and availability in the surveyed districts of Muchinga during the March-May 2023 survey

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Significant variations in the production of by-products, such as soybean cake, sunflower cake, maize bran, and rice bran, were observed across the surveyed districts (Table 3). Statistical analysis revealed substantial differences in production (0.231±1, $P < 0.05$), with Principal Component Analysis showing 73.2% variation on the first axis and 25.1% on the second axis (Figure 6). Notable production disparities ($P < 0.05$) were found between sunflower and rice as well as between soybean and maize. In the three districts where local salt was found (Isoka, Mpika, and Nakonde), the average production of this source did not show significant differences. Over the past five years, the processed local salt had a mean annual production of 36 ±5 metric tons (Table 4). The study classified feed ingredients into five nutrient categories: carbohydrates, proteins, lipids, vitamins, and minerals (Table 5). Carbohydrates topped the list with the highest average yearly production (21,762±0.4 metric tons), closely followed by proteins (20,757.4±0.4 metric tons). Lipid sources, mainly palm tree seed oil and sunflower oil, had an average annual production of 5,200±0.5 metric tons. Mineral sources, such as local salt, yielded an average of 828.5±0.44 metric tons per year. Among vitamin sources, pumpkin leaves were produced in considerable quantities in Mpika District, averaging 907±0.4 metric tons annually, although this was less than the production of carbohydrates, proteins, and lipids (Table 5).

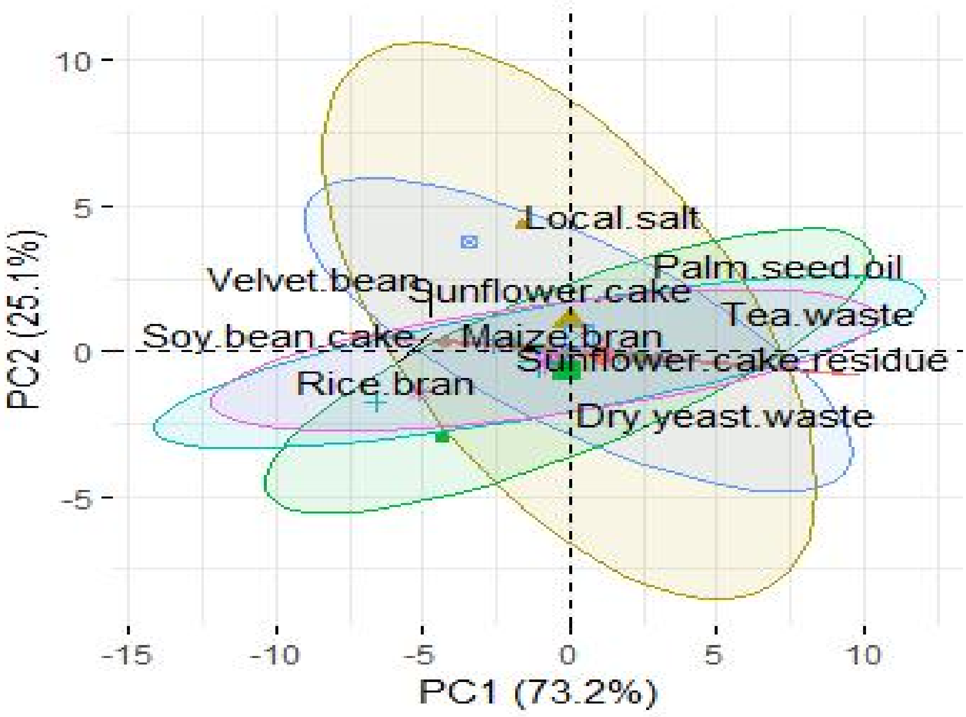

Figure 6: **PCA clustering of by-products and other ingredients based on their type and availability in the surveyed districts of Muchinga Province during the August-October 2023 survey**

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Research conducted in Southern Africa corroborates the results of this study, identifying maize as the principal fish feed ingredient at 43.6% of the total production [14]. The subsequent ingredients included cassava (21.2%), soybean (8%), and sunflower (8%). Furthermore, our findings are consistent with those conducted in Ghana [27] and Nigeria [28] and Kenya [29] where similar agriculture ingredients were screened with maize dominating the use ing aquafeed. Animal-derived materials, predominantly caterpillars, contributed 13% of the overall production. Lower quantities of by-products were observed, including maize bran (54%), sunflower cake (30%), and rice bran (11%). The least common ingredients, local salt (56%), and dried brewer yeast (44%), were limited to specific areas. These outcomes align with prior regional studies [2, 6].

The availability of fish feed ingredients in Muchinga Province exhibited significant seasonal variation. Plant-based components peaked during May and June, coinciding with the rainy season, whereas by-products remained accessible year-round. Caterpillar harvesting fluctuated across districts, with Mpika experiencing the maximum yield during the peak months. This trend aligns with the climatic patterns in Zambia, where seasonal rainfall influences the distribution and availability of natural resources across districts of the province [2, 4, 30].

Agro-ecological factors and seasonality substantially influenced the distribution of feed ingredients. Plant-based ingredient producers were primarily located in Agro-ecological Zone III, characterized by consistent rainfall and high crop yields. In contrast, Nakonde, situated in Agro-ecological Zone I, produced a more diverse range of ingredients. This pattern corresponds with FAO's classification of Zambia's agro-regions, emphasizing how environmental conditions dictate the availability and diversity of agricultural resources [4]. Despite the predominance of plant-based ingredients, certain ingredients like soybean, along with animal-derived sources such as fishmeal, faced notable challenges. These included competition with human consumption [31], limited awareness of alternative uses, and inadequate processing technologies. Consequently, there is a pressing need to intensify the production of both plant and animal feed ingredients. Exploring alternative protein sources, such as insects, presents a viable solution, given their nutritional richness in proteins and essential micronutrients. This intensification effort is further justified by ongoing investments in aquaculture, such as genetic improvement programs, which are expected to drive the industry's growth and escalate the demand for high-quality aquafeed [32, 33].

The study further revealed that fishmeal comprised 85.3% of animal-based ingredients, with caterpillars constituting the remainder. The predominance of fishmeal may be attributed to the availability of trash fish, particularly in local markets. These findings are consistent with previous studies in Benin and

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Tanzania, which similarly identified fish as the primary source of animal-based feed ingredients [34, 35]. Although seasonal, caterpillars represent a promising protein source and warrant further exploration to enhance their contribution to fish feed formulations.

However, the seasonal nature of caterpillar availability poses challenges for their consistent integration into fish feed. The study also highlighted that fish farmers utilizing commercial feed reported higher productivity compared to those relying on homemade alternatives. This discrepancy may stem from formulation and processing challenges, as most homemade feeds tend to be sinking feeds due to the absence of extrusion technology. Enhancing feed processing methods is crucial for producing nutritionally balanced and efficient floating feeds, which are better suited for intensive aquaculture systems.

Moreover, the high concentration of diverse plant ingredient producers and fish farmers in Mpika District suggests that improving access to local ingredients in rural areas could significantly enhance fish production in Zambia. These findings underscore the potential for advancing aquaculture sustainability through the optimized utilization and processing of both plant and animal feed ingredients. Strengthening supply chains, promoting feed innovation, and fostering farmer training programs will be critical in supporting the expansion of the aquaculture sector and ensuring the steady provision of quality feed materials.

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CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study on fish feed ingredient production and availability in Muchinga Province, Zambia, highlights the significant potential for advancing the aquaculture industry. Agricultural farmers are the primary producers of plant-based ingredients, contributing 56%, while processors supply by-products, accounting for 23%. Notably, the majority of farmers (85.2%) do not process their ingredients. Animal-based ingredients, sourced from farmers, processors, and forest gatherers, constitute 78.6% of the total production for aquaculture. However, only 17.1% of by-products are utilized as fish feed, with 41% allocated to livestock and 37.9% left unused. The average production estimates indicate approximately 19,693 MT/year for animal-based ingredients and 16,200 MT/year for plant-based ingredients. These findings underscore both the current contributions and the untapped potential of local resources in supporting aquaculture development in Zambia. Further research should prioritize documenting the nutritional profiles of unutilized ingredients and replicating similar studies in other regions to build a robust evidence base for sustainable fish feed formulation.

ACKNOWLEDGEMENTS

We sincerely thank the men and women who devoted their time to respond to the questionnaire. We also appreciate Kapasa Makasa University for the support provided in facilitating the ingredient and fish feed screening study in Muchinga Province, Zambia

DATA ACCESSIBILITY

The data that has been used in this study is available on request from the corresponding author.

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Table 1: **Type of ingredients mapped during the August - October 2023 screening study**

S/N	Type of Ingredient	Nutrient target	Source category
1	Sorghum	Carbohydrate	Plant
2	Rice	Carbohydrate	Plant
3	Maize	Carbohydrate	Plant
4	Finger millet	Carbohydrate	Plant
5	Cassava	Carbohydrate	Plant
6	Chikanda	Unknown	Plant
7	Soybeans	Protein	Plant
8	Sunflower	Protein	Plant
9	Cow peas	Protein	Plant
10	Velvet beans	Protein	Plant
11	Pumpkin leaves	Vitamins	Plant
12	Palm tree seed oil	Lipids	Plant
13	Sunflower cake	Protein	Plant
14	Sunflower extra residue	Lipids	Plant
15	Maize brain	Carbohydrate	Plant
16	Rice brain	Carbohydrate	Plant
17	Brewery waste	Protein	Processing
18	Caterpillar 1	Protein	Animal
19	Caterpillar 2	Protein	Animal
20	Local salt	Mineral	Animal

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Table 2: Mean production (MT) of animal ingredient sources in surveyed District during the March-May 2023 survey period. Dash symbol indicates no production

Districts	**Caterpillar 1**	**Caterpillar 2**
Isoka	8,035±2.40	3,022±2.42
Mpika	2,000±2.41	2,567±2.51
Chinsali	850±2.44	4,700±2.47
Nakonde	-	1,400±1.28
Overall mean	5,485±1.34[a]	2,629±1.32[b]

Table 3: Mean production (MT) of by-products ingredients of plant source in surveyed District during the August-October 2023 survey period. Dash symbol indicate indicates no production

Districts	**Sunflower cake**	**Rice bran**	**Soybean cake**	**Maize bran**
Isoka	260±0.52	-	-	239±0.71
Chinsali	148±0.53	168±0.51	220±0.68	240±0.64
Mpika	172±0.55	267±0.50	305±1.01	188±0.63
Nakonde	199±0.53	199±0.51	-	199±0.62
Overall Mean	**183.2**±0.51[a]	188.8±0.52[a]	**205**±0.51[b]	**213.2**±0.63[b]

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Table 4: Mean production (MT) of local salt in surveyed Districts during the August-October 2023 survey period. Dash symbol indicates no production

Districts	Local salt
Isoka	24.4±5.71
Mpika	-
Nakonde	59.74±5.72
Mean	**34.2±5.16**
Isoka	45.2±5.70
Mpika	77.9±5.69
Nakonde	54.8±5.55
Mean	**39.3±5.49**
Isoka	85.1±5.64
Mpika	93.3±5.67
Nakonde	20.5±5.55
Mean	**36.3±5.45**
Overall Mean	**35.5±5.23**

Table 5: Mean production (MT) of targeted nutrient during the August-October 2023 survey

Target Nutrient	Average production
Carbohydrates	21,762±0.43[a]
Proteins	20,757.4±0.41[a]
Lipids	5,200±0.45[b]
Vitamins	907±0.43[c]
Minerals	828.5±0.44[c]

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Table 6: Availability of ingredients in the surveyed Districts, during the August-October 2023 survey. Cross sign indicates availability

Source category	Type	Isoka	Mpika	Nakonde	Chinsali
Plant	Maize (43.6%)	X	X	X	X
	Rice (6.4%)		X	X	X
	Sorghum (2%)	X			
	Finger millet (3.1%)	X			
	Cassava (9.2%)		X	X	X
	Chikanda (2.8%)		X	X	X
	Soy beans (8%)	X	X	X	X
	Sunflower (8.4%)	X	X	X	X
	Cow peas (1.9%)	X		X	X
	Velvet beans (1.6%)	X		X	
	Caterpillar 1 (6%)		X	X	X
	Caterpillar 2 (7%)		X		
Animal					
By-products	Sunflower cake (30%)	X	X	X	X
	Brewery waste (3%)			X	
	Sunflower extra residue (1%)				
	Maize brain (54%)	X	X	X	X
	Rice brain (11%)		X	X	X
	Brewery waste (3%)				
	Palm seed oil (2%)			X	X
Others	Local salt (56%)		X	X	X

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Table 7: Seasonality of ingredient availability in the surveyed Districts during the August-October 2023 survey. Cross sign indicates seasonality of availability

Source category	Ingredient	Seasonality present		Month of Availability
		All year	Not all year	
	Maize		X	May - June
	Rice	x		May - June
	Sorghum		X	May - June
	Finger millet		X	May - June
	Cassava	X		January - December
	Chikanda	X		January - December
Plant	Soy beans		X	May - June
	Sunflower		X	May - June
	Cow peas		X	May - June
	Velvet beans		X	May - June
	Pumpkin leaves		X	May - June
	Palm tree seed		X	January - December
	Sunflower cake	X		January - December
	Tea waste (red dust)	X		January - December
By-products	Sunflower extra residue	X		January - December
	Maize brain	X		January - December
	Rice brain	X		January - December
	Brewery waste	X		January - December
	Palm seed oil	X		January - December
Animal	Caterpillar 1		X	May - June
	Caterpillar 2		X	May - June
Others	Local salt	X		January - December

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