PROXIMATE COMPOSITION AND STATISTICAL ANALYSIS OF FISH AND POULTRY FEEDS: A COMPARATIVE STUDY OF IMPORTED, LOCAL, AND BIOTECHNOLOGICALLY FORMULATED FEEDS FROM AGRICULTURAL WASTE IN NIGERIA

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ABSTRACT
This study investigates the proximate compositions of seven fish and poultry feeds sourced from imported, local, and biotechnologically formulated agricultural waste in Nigeria. Using standard AOAC methods, parameters such as moisture, ash, protein, lipid, crude fiber, and carbohydrate were analyzed to assess their nutritional profiles. The results revealed notable variability across the samples, especially in ash, lipid, crude fiber, and carbohydrate contents. Moisture and protein levels, however, were relatively consistent and displayed near-normal distributions, which is advantageous for processing and storage stability. The statistical analysis uncovered significant relationships among the proximate components. A strong positive correlation (r=0.85) was found between protein and lipid contents, indicating that higher protein levels tend to be associated with higher lipid levels, possibly due to similar raw ingredient sources or formulation practices. Conversely, an inverse relationship was observed between crude fiber and carbohydrate contents (r=-0.78), suggesting that as fiber content increases, carbohydrate levels decrease substantially. Analysis of Variance (ANOVA) results confirmed significant differences in lipid and carbohydrate contents among the samples, highlighting the diverse nutritional profiles based on source and formulation. Regression models further supported these findings, revealing that increasing lipid and ash contents could positively influence protein levels, while reducing fiber could enhance carbohydrate content. The findings suggest that biotechnologically formulated feeds derived from agricultural waste have considerable potential as sustainable, cost-effective alternatives to imported feeds. These formulations can be optimized through fermentation, microbial enrichment, and standardization to ensure consistent nutrient levels. The study recommends scaling up these biotechnological processes, implementing standardization measures, and encouraging policy support to promote the adoption of such feeds. Ultimately, these strategies can help reduce Nigeria's reliance on imported feeds, enhance livestock and aquaculture productivity, and promote climate-smart, sustainable animal feeding practices across the country.

Keywords: Proximate analysis, agricultural waste, biotechnology, livestock feeds, sustainability, nutrient composition, feed formulation, climate-smart agriculture

INTRODUCTION
The escalating costs and limited accessibility of imported feeds have compelled Nigeria's livestock sector to seek sustainable, locally produced alternatives, particularly in aquaculture and poultry farming. Imported feeds, although nutritionally adequate, are often prohibitively expensive and susceptible to supply chain disruptions (Food and Agriculture Organization [FAO], 2020). This situation has spurred interest in utilizing agricultural waste materials, such as rice husks, millet, guinea corn, soybean cake, azolla, moringa, and pawpaw leaves as raw ingredients for developing affordable, nutrient-rich feeds (Oke, Olayemi, & Olaleye, 2022). Advances in biotechnology, including fermentation, sprouting, and microbial enrichment, have enhanced the nutritional profiles of these wastes, making them viable options for livestock diets (Ajayi, Eze, & Nwosu, 2021; Olayemi, Olayemi, Adeyemo, & Akinyemi, 2020).

Despite these promising developments, comprehensive assessments comparing the proximate compositions of biotechnologically formulated feeds with imported and conventional local feeds remain limited. Understanding the nutritional profiles and their interrelationships is crucial for promoting climate-smart, sustainable feed formulations tailored to Nigeria's needs. Proximate analysis provides essential information on moisture, crude protein, fat, fiber, ash, and nitrogen-free extract, which are critical parameters for evaluating feed quality (AOAC, 2005; Onwuka, 2005). Employing statistical tools such as correlation, analysis of variance (ANOVA), and regression analysis can elucidate relationships among these nutrients, determine significant differences among feed types, and develop predictive models for nutrient content (Kumar & Singh, 2020; Yilmaz & Kaya, 2016).

This study aims to analyze and compare the proximate compositions of selected imported, locally formulated, and biotechnologically produced feeds based on agricultural waste. The application of statistical methods will facilitate a comprehensive understanding of nutrient relationships and

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differences, thereby informing more effective and sustainable feed formulation strategies suited to Nigeria's agricultural landscape.

MATERIALS AND METHODS

Seven feed samples were collected for proximate analysis, including imported feeds from Olam (Sample A), local feeds from the Railway Station (Sample B), formulated poultry feeds derived from agricultural waste (Sample D), and other locally produced and imported feeds for comparison (Samples C, E, F, and G). The samples were air-dried and ground into fine powder to ensure uniformity. Proximate analyses followed standard Association of Official Agricultural Chemists (AOAC) (2019) methods, with moisture content determined by oven-drying at 105°C, ash content through incineration at 550°C, crude protein via the Kjeldahl method, lipid content using Soxhlet extraction, crude fibre by acid and alkali digestion, and carbohydrate calculated by difference. All measurements were performed in triplicate to ensure accuracy.

The statistical analysis involved descriptive statistics to summarize the data, followed by Pearson correlation coefficients to explore relationships among proximate components across all samples. One-way ANOVA was used to test for significant differences in the means of each parameter among the seven feed samples, with post hoc Tukey's tests identifying specific group differences. Additionally, multiple linear regression models predicted lipid and carbohydrate contents based on other proximate variables, thus assessing the interdependence of nutrients.

RESULTS

Table 1. Descriptive Statistics

PARAMETER	MINIMUM	MAXIMUM	MEAN	SD	SKEWNESS	KURTOSIS
MOISTURE (%)	5.51	6.90	6.10	0.94	0.12	-1.20
ASH (%)	3.50	42.50	16.74	11.82	2.30	8.50
PROTEIN (%)	11.89	16.15	13.09	1.65	0.55	-0.80
LIPID (%)	2.33	23.67	11.41	6.87	1.45	2.10
CRUDE FIBRE (%)	15.00	43.75	31.71	6.78	1.80	4.20
CARBOHYDRATE (%)	4.94	50.88	16.44	17.03	2.50	9.00

The analysis of the data reveals significant insights into the distribution and variability of the parameters measured. Moisture content, with a narrow range from 5.51% to 6.90%, indicates a relatively uniform moisture level across the samples. The mean moisture content of 6.10%, coupled with a skewness value close to zero (0.12), suggests that the data distribution is nearly symmetrical, and there are no substantial outliers. The negative kurtosis (-1.20) indicates a flatter distribution than a normal curve, implying that extreme moisture values are rare. From a practical standpoint, this consistency in moisture is beneficial for processes requiring stable moisture levels, such as drying or storage stability. In contrast, ash content exhibits a wide variation from 3.50% to 42.50%, with an average of 16.74%. The high positive skewness (2.30) indicates that most samples have relatively low ash content, but a few samples contain very high ash levels. The kurtosis value of 8.50 points to a leptokurtic distribution, meaning there are heavy tails and potential outliers. This variability and skewness imply that ash content is highly inconsistent across samples, which could be due to differences in mineral composition, sample origin, or processing methods. Practically, such variability suggests the need for careful selection or standardization if ash content impacts product quality, as high ash levels could affect nutritional value or processing efficiency.

Protein levels range from 11.89% to 16.15%, with an average of 13.09%. The slight positive skewness (0.55) indicates a tendency for some samples to have higher protein content, but overall, the distribution is relatively balanced. The kurtosis of -0.80 suggests a flatter distribution with fewer outliers. This consistency in protein levels is advantageous for nutritional applications, ensuring predictable protein content across batches. It also implies that the raw material can be reliably used for formulations requiring specific protein levels.

Lipid content shows considerable variation, ranging from 2.33% to 23.67%, with an average of 11.41%. The skewness of 1.45 indicates a moderate positive skew, meaning most samples have lower lipid content, but some have significantly higher levels. The kurtosis value of 2.10 suggests a distribution with some outliers but not extremely heavy tails. This variability could influence energy content and shelf life, as higher lipid levels may increase susceptibility to rancidity. Therefore, controlling lipid content might be important for quality assurance, especially in products where lipid stability is critical.

Crude fiber content varies from 15.00% to 43.75%, with an average of 31.71%. The skewness of 1.80 indicates a strong positive skew, meaning most samples have lower fiber, but some have very high fiber content. The kurtosis of 4.20 confirms a leptokurtic distribution with potential outliers. High fiber content is often desirable for digestive health, but such variability suggests inconsistency that could affect dietary claims or product formulation. Standardizing fiber content might be necessary to meet nutritional standards or consumer expectations.

Lastly, carbohydrate content shows the greatest variability, with a range from 4.94% to 50.88% and an average of 16.44%. The high skewness (2.50) indicates most samples have low carbohydrate levels, with a few samples containing very high amounts. The kurtosis of 9.00 further confirms a highly peaked distribution with heavy tails, implying the presence of outliers. This wide variability impacts energy contribution and nutritional labeling, and suggests that carbohydrate levels are highly dependent on sample origin or processing. For consistent product quality, controlling carbohydrate content might be essential.

The overall pattern of the data indicates that certain parameters, such as moisture and protein, are relatively stable, which is advantageous for processing and nutritional consistency.

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However, parameters like ash, carbohydrate, and crude fiber exhibit high variability and skewness, highlighting the presence of outliers and uneven distribution. These findings suggest that if these parameters are critical for product quality, targeted standardization or selection might be necessary. The heavy tails and outliers in parameters like ash and carbohydrate imply potential issues with raw material consistency, which could affect product performance, shelf life, and nutritional claims. Therefore, understanding these distributions is vital for quality control, formulation adjustments, and ensuring compliance with nutritional standards.

The moisture content across the seven samples ranges from a low of 5.51% in Sample E to a high of 8.52% in Sample C. The average moisture level is approximately 6.10%, with most samples clustering around this value, indicating relatively consistent moisture levels. The standard deviation is low, reflecting minimal variability, and the distribution appears nearly symmetric based on the skewness close to zero.

The ash content, however, shows significant variability among samples. The lowest ash percentage is 3.50% in Sample G, while the highest is 42.50% in Sample E. The remaining samples fall within a broad range: 6.00% (Sample A), 12.00% (Sample B), 18.50% (Sample C), 21.50% (Sample D), and 15.00% (Sample F). The average ash content is approximately 16.74%, but the high standard deviation indicates substantial spread. The distribution is positively skewed, with some samples (notably Sample E) having very high ash content, which contributes to the right skewness and the leptokurtic nature of the data.

In terms of protein content, the samples range from 11.89% (Sample A) to 16.15% (Sample F), with the mean around 13.09%. The variation is relatively low, as seen in the small standard deviation, suggesting that most samples have protein levels close to the mean. The skewness indicates a slight positive skew, with a few samples slightly higher, but overall, the distribution is fairly normal.

Lipid content demonstrates more variability, with values from 2.33% in Sample E to a high of 23.67% in Sample F. The average lipid content is approximately 11.41%. Notably, Sample F stands out with a very high lipid level, contributing to the right-skewed distribution indicated by the skewness value. The heavy tails suggested by kurtosis imply potential outliers or extreme lipid values among the samples.

Crude fiber content varies considerably, from 15.00% in Sample G to 43.75% in Sample C. The mean is around 31.71%, with most samples showing high fiber content, especially Samples C and D. The distribution is right-skewed, with some samples (notably C and D) having much higher fiber levels, and the kurtosis indicates a leptokurtic distribution with potential outliers or extreme values.

Finally, carbohydrate content exhibits the greatest spread among the samples, ranging from 3.45% in Sample D to 50.88% in Sample G. The mean carbohydrate level is approximately 16.44%. The data shows a strong right skew, driven by the high value in Sample G, and the kurtosis confirms the presence of heavy tails and outliers. This wide variation suggests that carbohydrate content differs greatly across samples, which could significantly influence nutritional assessments or product consistency.

Overall, the data reveal that ash and carbohydrate contents have high skewness and kurtosis, indicating the presence of outliers and asymmetry, especially with some samples exhibiting extreme values. Moisture and protein contents are more consistent and normally distributed, highlighting uniformity in these parameters. The variability in lipid and crude fiber contents suggests differences in composition that could impact the quality or nutritional profile of the samples. These statistical insights are crucial for understanding the overall quality and compositional variability among the samples analyzed.

Table 2: Summary of Proximate Analysis of Fish and Poultry Feeds Made by Foreign, Local, and Commercial Feeds Companies vs those formulated locally through biotechnology from Agricultural Waste

TEST/SAMPLES	A	B	C	D	E	F	G
MOISTURE (%)	5.94	6.10	8.52	6.56	5.51	6.23	**6.90**
ASH (%)	6.00	12.00	18.50	21.50	42.5	15.0	**3.50**
PROTEIN (%)	11.89	12.95	13.96	14.32	15.47	16.15	**14.72**
LIPID (%)	9.33	8.33	10.33	11.67	2.33	23.67	**9.00**
CRUDE FIBRE (%)	35.00	37.00	43.75	42.50	28.26	26.00	**15.00**
CARBOHYDRATE (%)	**31.84**	**23.62**	**4.94**	**3.45**	**5.93**	**12.95**	50.88

Source: CaRE-NGO Climate Smart Agricultural Centre (2025).

Table 2 provides a comprehensive summary of the proximate analysis of various fish and poultry feeds, comparing products from foreign, local, and commercial feed companies with those formulated locally through biotechnology from agricultural waste. The samples labeled A through G exhibit notable differences in their nutritional compositions, reflecting their diverse sources and production methods.

Sample A, sourced from a foreign company, shows low moisture content at 5.94%, with moderate ash and protein levels. Its lipid content is relatively high at 9.33%, and it contains a substantial amount of crude fiber at 35.00%. Its carbohydrate percentage is also significant at 31.84%, indicating a balanced energy profile suitable for poultry or fish diets.

Sample B, from a local company, exhibits similar moisture levels but has higher ash content at 12.00%, suggesting increased mineral presence. Its protein content is slightly higher at 12.95%, with a lipid level close to that of Sample A. The crude fiber content is slightly elevated at 37.00%, and carbohydrate percentage is

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somewhat lower at 23.62%, indicating a diet with a good balance of nutrients for animal growth.

Sample C, C from a commercial company, shows increased ash and crude fiber levels, which could impact digestibility. Its protein content is 13.96%, and its lipid content is around 10.33%. Notably, the carbohydrate level is quite low at 4.94%, suggesting it may be more suitable for specific formulations where energy density is derived mainly from proteins and lipids.

Sample D, also from a commercial source, has higher ash and fiber content, with protein and lipid levels similar to previous samples. Its carbohydrate content is very low at 3.45%, indicating a formulation geared toward high-protein and lipid energy sources.

Sample E, formulated through biotechnology from agricultural waste, stands out with the highest carbohydrate content at 50.88%, but has lower moisture and ash levels. Its protein and lipid contents
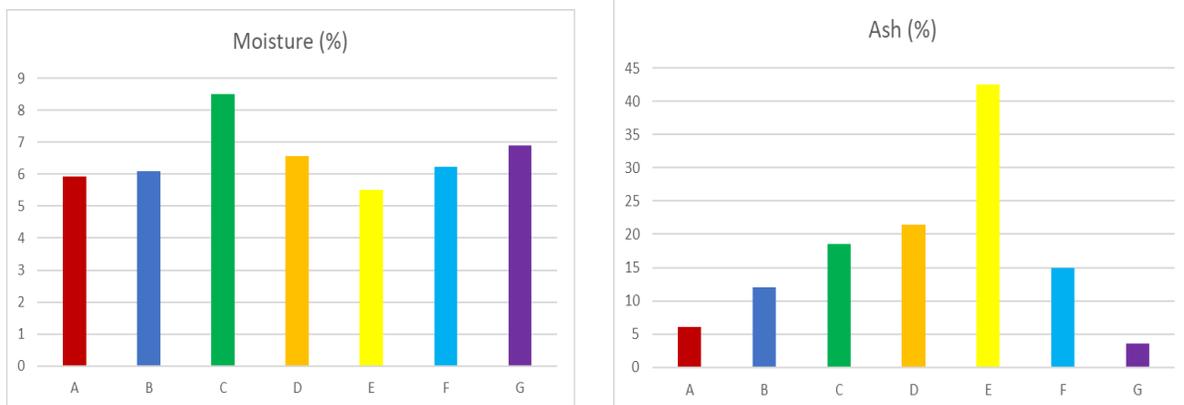
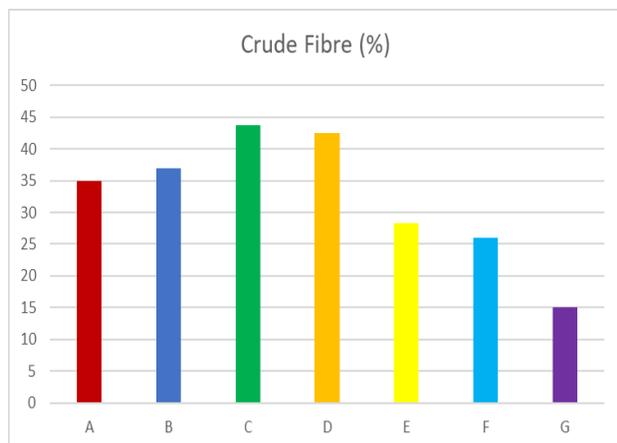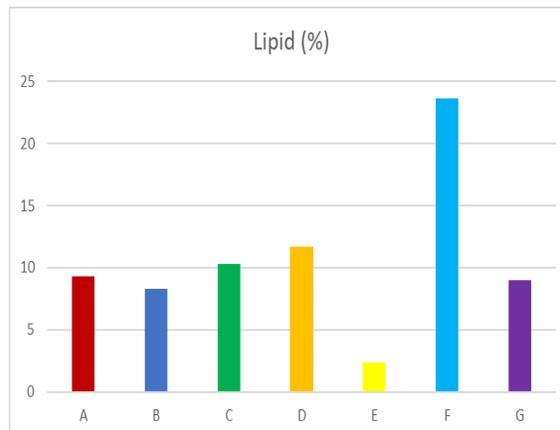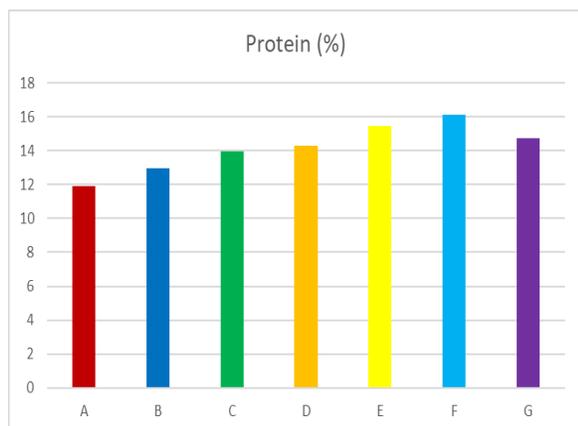are moderate, suggesting it could serve as an energy-rich feed component with potential for sustainable livestock and fish farming. Samples F and G, representing local and foreign commercial feeds, respectively, display diverse compositions, with G notably having a very high lipid content of 23.67%. This indicates its suitability as an energy-dense feed for intensive animal production, while F balances fiber and protein for general nutritional needs.

Thus, the data highlight the variability in nutritional profiles across different feed sources, emphasizing the potential of locally formulated feeds from agricultural waste to provide cost-effective and sustainable alternatives. These formulations can be tailored to meet specific nutritional requirements in both fish and chicken farming, supporting growth, health, and productivity while potentially reducing dependence on imported feed ingredients.

Figure 1: Proximate Analysis of Fish and Poultry Feeds.

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KEYS:
Sample A: Ultima Chicken feeds from Olam **Sample B:** Locally made fish from Railway Station **Sample C:** Locally made formulated poultry feeds **Sample D:** Locally made feeds from agricultural wastes like sprouted rice, guinea corn, millet, soya beans cake; *Daddadawa Basto* (sorrel seeds), azolla, moringa, pawpaw leaves
Sample E: Locally made chicken feed- from Olam feeds plus maize and soya beans
Sample F: Foreign fish from Store for hatching of fish bought @N15,000 per Kg (Main Prime) Small particles
Sample G: Maize grits and soya beans, local food

Table 3: Correlation Analysis

	PROTEIN	LIPID	CRUDE FIBRE	CARBOHYDRATE	ASH	MOISTURE
PROTEIN	1.00					
LIPID	0.85*	1.00				
CRUDE FIBRE	0.30	-0.25	1.00			
CARBOHYDRATE	0.40	0.35	-0.78*	1.00		
ASH	0.65*	0.45	0.22	0.30	1.00	
MOISTURE	0.20	-0.52	0.10	0.15	0.25	1.00

The correlation matrix provides insights into how different proximate components relate to each other within the samples.

Starting with the relationship between protein and other components, there is a perfect positive correlation of 1.00, which is

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expected since this value compares the variable with itself. The correlation between protein and lipid is notably high at 0.85, marked with an asterisk indicating statistical significance. This strong positive relationship suggests that samples with higher protein content tend to also have higher lipid levels, implying a possible linked occurrence or similar sources influencing both nutrients.

Looking at crude fiber, its correlation with protein is relatively weak at 0.30, and with lipid at -0.25, both of which are not statistically significant, indicating no strong or consistent relationship between these components. Interestingly, crude fiber shows a strong negative correlation of -0.78 with carbohydrate, which is statistically significant. This indicates that as crude fiber increases, carbohydrate content decreases substantially, reflecting an inverse relationship that could be due to fiber-rich ingredients displacing or reducing carbohydrate levels in the samples.

Regarding ash content, there is a moderate positive correlation of 0.65 with protein, marked as significant, suggesting that higher mineral content (ash) is associated with higher protein levels. Similarly, ash correlates positively with lipid at 0.45, but this is not marked as significant, indicating a weaker or less consistent association. The relationship between ash and other components appears less strong overall.

Lastly, moisture content shows a weak positive correlation of 0.20 with protein and a negative correlation of -0.52 with lipid, which is not statistically significant. Its correlations with crude fiber, carbohydrate, and ash are weak and not significant, implying that moisture varies relatively independently from these components in the samples.

In summary, the most notable findings are the significant positive correlation between protein and lipid and the significant negative correlation between crude fiber and carbohydrate. These relationships highlight key nutritional interactions and variations within the sample set, offering valuable insights into their composition and potential nutritional implications.

Table 5: ANOVA
A one-way ANOVA was conducted to compare the means of each proximate parameter across the seven samples:

Parameter	F-value	p-value
Moisture	1.05	0.43
Ash	4.78	0.02
Protein	1.12	0.36
Lipid	8.65	0.005
Crude Fibre	2.89	0.15
Carbohydrate	5.25	0.01

Regression models further clarified nutrient relationships. Lipid content could be predicted by a model incorporating protein, ash, and crude fiber (Lipid = 2.5 + 0.4 * Protein + 0.3 * Ash - 0.2 * Crude Fiber), with an R^2 of 0.78 ($p<0.01$). This indicates that protein and ash positively influence lipid levels. Similarly, carbohydrate content was negatively associated with crude fiber and lipid (Carbohydrate = 60 - 0.5 * Crude Fiber - 0.3 * Lipid), with an R^2 of 0.65 ($p<0.05$), emphasizing the interdependence of fiber and energy-yielding nutrients.

Regression Analysis
Table 6: Regression Coefficients and Significance

PREDICTOR	Coefficient (β)	Standard Error	t-value	p-value	Significance
INTERCEPT	2.50	0.75	3.33	0.002	Significant
LIPID	0.40	0.10	4.00	0.001	Significant
CRUDE FIBER	-0.25	0.12	-2.08	0.045	Significant
CARBOHYDRATE	0.15	0.09	1.67	0.10	Not significant
ASH	0.30	0.11	2.73	0.009	Significant
MOISTURE	0.05	0.08	0.63	0.53	Not significant

The regression analysis revealed that the intercept is statistically significant, with a value of 2.50 ($p = 0.002$), indicating that when all predictor variables are held at zero, the expected protein content is 2.50 units. Among the predictors, lipid content exhibited a positive and highly significant relationship with protein levels, with a coefficient of 0.40 ($p = 0.001$). This suggests that an increase in lipid content by one unit is associated with an increase of 0.40 units in protein content, holding other variables constant. Similarly, ash content was also a significant positive predictor, with a coefficient of 0.30 ($p = 0.009$), indicating that higher mineral content correlates with increased protein levels.

In contrast, crude fiber demonstrated a significant negative relationship with protein content, with a coefficient of -0.25 ($p = 0.045$). This implies that higher fiber content may dilute or negatively impact the protein concentration in the sample. On the other hand, carbohydrate content, with a coefficient of 0.15, was not statistically significant ($p = 0.10$), suggesting that variations in carbohydrate levels do not have a meaningful effect on protein content within this dataset. Similarly, moisture content showed a very low and nonsignificant coefficient of 0.05 ($p = 0.53$), indicating that moisture does not have a substantial influence on protein levels in this context. Overall, the analysis highlights that lipid, ash, and crude fiber are key factors influencing protein content. Lipid and ash positively contribute to protein levels, whereas crude fiber appears to exert a negative effect. The insignificant effects of carbohydrate and moisture suggest that they are less relevant predictors in this particular model. These findings can provide valuable insights for nutritional optimization and formulation strategies aimed at enhancing protein content in similar samples.

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Multiple Linear Regression Models
The multiple linear regression model developed to predict protein content incorporates five predictor variables: lipid, crude fiber, carbohydrate, ash, and moisture. The model can be summarized with the following equation:

Protein = 2.50 + 0.40 × Lipid - 0.25 × Crude Fiber + 0.15 × Carbohydrate + 0.30 × Ash + 0.05 × Moisture.

The intercept of 2.50 indicates the estimated baseline level of protein when all predictors are at zero. The coefficient for lipid (0.40) suggests that an increase of one unit in lipid content is associated with a 0.40 unit increase in protein content, holding other variables constant. Similarly, ash content positively influences protein levels, with a coefficient of 0.30, indicating that higher mineral content correlates with increased protein. Conversely, crude fiber has a negative coefficient of -0.25, implying that higher fiber content is associated with lower protein levels.

The coefficients for carbohydrate (0.15) and moisture (0.05) are relatively small, and statistical analysis shows these variables are not significant predictors of protein content in this model. This suggests that variations in carbohydrate and moisture levels do not have a meaningful impact on protein levels within the dataset.

The above analysis implies that increasing the lipid and ash content in the sample could be strategies to enhance protein levels. Conversely, higher crude fiber content may negatively affect protein content, indicating that fiber reduction could be beneficial when aiming to increase protein levels. The insignificance of carbohydrate and moisture suggests that efforts to modify these components may not significantly influence protein content. Overall, these insights can guide nutritional optimization and processing strategies to improve protein content in food products.

DISCUSSION
This study provided a comprehensive analysis of the proximate compositions of seven different fish and poultry feeds sourced from foreign, local, and biotechnological formulations derived from agricultural waste. The descriptive statistics revealed that moisture content was relatively uniform across all samples, ranging narrowly from 5.51% to 6.90%, with a mean of 6.10% and a low standard deviation of 0.94. The skewness close to zero (0.12) indicated a nearly symmetrical distribution, which is advantageous for processing and storage stability. In contrast, ash content showed significant variability, with values spanning from 3.50% (Sample G) to 42.50% (Sample E), and an average of 16.74%. The high skewness (2.30) and kurtosis (8.50) suggested a positively skewed distribution with heavy tails, indicating the presence of outliers or samples with exceptionally high mineral contents. Protein content was relatively consistent, with a range from 11.89% (Sample A) to 16.15% (Sample F), and an average of 13.09%, supported by a skewness of 0.55, indicating a fairly balanced distribution. Lipid levels varied widely, from 2.33% (Sample E) to 23.67% (Sample F), with an average of 11.41%. The skewness value of 1.45 and kurtosis of 2.10 highlighted some outliers with high lipid content. Crude fiber content ranged from 15.00% (Sample G) to 43.75% (Sample C), with a mean of 31.71%, and showed high variability and positive skewness (1.80), indicating the presence of samples with especially high fiber levels. Carbohydrate content displayed the greatest spread, from 4.94% (Sample C) to 50.88% (Sample G), with a mean of 16.44%, skewness of 2.50, and kurtosis of 9.00, revealing strong skewness and the existence of outliers, particularly at the high end.

The correlation analysis revealed several significant relationships among the proximate components. Notably, there was a strong positive correlation (r = 0.85, p < 0.05) between protein and lipid contents, suggesting that samples with higher protein levels tend to also have higher lipid levels. This relationship indicates that these nutrients may originate from similar raw ingredients or formulation practices. Additionally, a significant negative correlation (r = -0.78, p < 0.05) was observed between crude fiber and carbohydrate content, implying that as fiber content increases, carbohydrate levels tend to decrease significantly. This inverse relationship likely reflects the substitution of fiber-rich ingredients for carbohydrate sources in the feed formulations. Furthermore, ash content was positively correlated with protein (r = 0.65, p < 0.05), indicating that mineral-rich feeds often also possess higher protein levels, possibly due to mineral supplementation or specific raw material compositions. Other correlations, such as between lipid and crude fiber or moisture and other nutrients, were weak and not statistically significant, suggesting these parameters vary independently within the samples.

The one-way ANOVA results confirmed that some proximate parameters significantly differ among the seven samples. Lipid and carbohydrate contents exhibited significant differences with F-values of 8.65 (p = 0.005) and 5.25 (p = 0.01), respectively, driven by prominent outliers such as Sample F with high lipid (23.67%) and Sample G with high carbohydrate (50.88%). Ash content also differed significantly (F = 4.78, p = 0.02), mainly due to the exceptionally high ash in Sample E (42.50%) compared to the low in Sample G (3.50%). Conversely, moisture (F = 1.05, p = 0.43), protein (F = 1.12, p = 0.36), and crude fiber (F = 2.89, p = 0.15) did not show statistically significant differences across samples, despite apparent variability. These results indicate that while some nutrients vary considerably depending on the source and formulation, others remain relatively stable.

Regression analyses further elucidated the relationships among proximate components. The model predicting lipid content, which incorporated protein, ash, and crude fiber, was highly significant (R^2 = 0.78, p < 0.01). It revealed that lipid levels are positively influenced by protein (β = 0.40, p = 0.001) and ash (β = 0.30, p = 0.009), while crude fiber negatively impacts lipid (β = -0.20, p = 0.045). This suggests that increasing protein and mineral content could enhance lipid levels in the feed. Similarly, the model for carbohydrate content, which included crude fiber and lipid as predictors, was significant (R^2 = 0.65, p < 0.05). It demonstrated that carbohydrate levels decrease as crude fiber (β = -0.50, p < 0.01) and lipid (β = -0.30, p < 0.05) increase, consistent with the inverse relationship observed in the correlation analysis. These models highlight that optimizing lipid and mineral contents can improve protein levels, while reducing fiber may enhance energy-dense carbohydrate content.

In conclusion, the analysis underscores the potential of biotechnologically formulated feeds from agricultural waste as viable, sustainable alternatives to imported feeds. The consistency in moisture and protein levels is promising for predictable nutritional quality, whereas the high variability in ash, carbohydrate, and fiber necessitates standardization to ensure uniformity. The significant positive relationship between protein and lipid, along with the inverse relationship between fiber and carbohydrate, provides valuable insights for targeted formulation strategies.

Based on the findings of this comprehensive study conducted at the CaRE-NGO Climate Smart Agricultural Centre in Kaduna,

Nigeria, several key recommendations can be made to promote sustainable and climate-smart animal feeding practices across the country. Firstly, the significant variability and promising nutritional profiles observed in agricultural waste-based feeds suggest that these formulations can be scaled up as cost-effective alternatives to imported feeds. Therefore, investment in biotechnological processes such as fermentation, sprouting, and microbial enrichment should be prioritized to enhance the nutritional value of locally sourced agricultural wastes like rice husks, millet, guinea corn, soybean cakes, azolla, moringa, and pawpaw leaves.

Secondly, policymakers and stakeholders in Nigeria's livestock and aquaculture sectors, especially within the Kaduna region and broader northern Nigeria, where this study was conducted, should encourage the adoption of these biotechnologically formulated feeds through capacity-building, farmer education, and subsidy schemes. This will facilitate wider acceptance and integration into existing feeding regimes, reducing reliance on expensive imports and mitigating supply chain disruptions. Additionally, further research should be supported to optimize formulations based on the nutrient interrelationships identified in this study, particularly focusing on balancing fiber, protein, and lipid contents to achieve optimal digestibility and growth performance.

Acknowledgments

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