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Some engineering properties and nutrient composition of selected pelletized fish feed in Nigeria

O C Erinle[1], A P Olalusi [2], A T Olayanju[1], A A Okunola[1] and F O Ajao[1]

[1] Agricultural and Bio-system Engineering Department, Landmark University, P.M.B 1001, Omu-Aran, Kwara State, Nigeria.
[2] Agricultural and Environmental Engineering Department, Federal University of Technology Akure, P.M.B. 704, Akure, Ondo State, Nigeria.

E-mail: erinle.oluwakemi@lmu.edu.ng

Abstract. This research work is aimed to study the engineering properties (Physical, Thermal and Mechanical), and nutritional qualities of selected pelletized fish feed in Nigeria. This is to provide a database of engineering properties of fish feed pellets in Nigeria, which can be required for further handling and processing operations. Three locally produced feeds in Nigeria (Kwara P1, Ondo P2, and Edo P3) were selected. The engineering properties analysed include unit density, bulk density, expansion ratio, colour, sinking velocity, water stability, water absorption index, water solubility index, pellet durability index, thermal conductivity, resistivity and diffusivity. The extrudates and pellets were subjected to nutritional composition analyses, which include: crude protein, crude fat, total carbohydrate, ash and crude fibre, Potassium, Phosphorus and Calcium. The unit density, bulk density and expansion ratio of the pellets ranges from 407.08 – 518.36 kg.m^{-3}, 267.33 – 271.93 kg.m^{-3} and 12.73 – 16.40 %, respectively. The pellet durability index and water stability ranges from 41.07 - 68.60 % and 12.40 – 35.96 mins but P2 had the highest expansion rate (25.55%). The Potassium, Zinc, crude fibre and thermal properties had no significant effect on the feeds at p-level of 5%. The data obtained from this study creates a reference line for the design and development of handling machines, and storage facilities.

1. Introduction

As one of agriculture's fastest growing food production industries around the globe, aquaculture has captured the eye of many researchers presently working to enhance several fields involving fish manufacturing. The industry has a substantial role in the economy of many countries, by offering revenue, better jobs, decreasing the percentage of unemployment and improving the intake of protein [1].

Aquaculture in Nigeria is experiencing several difficulties that impede its development. Two of the main fields are, seeds of quality (fingerlings) and fish feed of high quality**.** As the aquaculture sector is growing, the demand for aqua-feed is also increasing. It is challenging to obtain high-quality fish feeds produced in Nigeria, imported feeds are mostly used in Nigeria. In spite of the recent measures to promote the native feed business, their output is still very small to satisfy the aquaculture industry's requirements. This is due to the elevated feed price created by the devaluation of Naira and the absence of processing and storage technology [2].

Pelletizing is the way to compress solid particles into a pellet's form.[3]. To process fish feed, a well-controlled procedure is necessary, in order to achieve acceptable requirements for physical product quality and density. The physical quality of fish feeds is important because of improved handling, storage and pneumatic systems. Improper handling exposes the feed to stress that might increase abrasion and product loss [1]. Pellet quality relies on the materials used, processing equipment type (pelletizer or extruder), processing factors, size and shape. All these aforementioned factors have impact on the feed's physical, nutritional and physiochemical properties. It is therefore very essential to know the pellets physical, nutrient and mechanical behaviour in order to select the best technique and monitor the process of producing high-quality fish feed [4,5].

In Nigeria, there is a need for data on the physical and mechanical properties of good fish feed pellets produced. These data are necessary for processing, transportation, packaging of fish feed in Nigeria, therefore, the aim of the research is to study the engineering properties (Physical, Thermal, and Mechanical), nutritional qualities of selected (Landmark University pelletized feed, and two locally produced) pelletized fish feed in Nigeria.

2. Materials and Method

2.1. Materials

The fish feed used had very similar formulation (fish meal 30%, blood meal 10%, soymeal or groundnut cake 25%, maize 20%, fish premix and binder (15%) they were produced in three geo-political zones of Nigeria. The feeds (4mm die size) were given codes namely: P1, P2, and P3. The Landmark University, Kwara State (North-Central geo-political zone) pelletizer was given code P1 while codes P2 and P3 were for major feed companies in Edo (South-South geo-political zone) and Ondo State (South-West geo-political zone), respectively.

2.2. Experimental Design

All pellet characteristics such as the rate of expansion, dimensions, sinking velocity, and the density were evaluated in triplicates.

2.3. Evaluation of Physical and Mechanical Properties of the feed

2.3.1. Moisture Content. The moisture content of the pelleted feed was evaluated according to the AOAC technique 44-19 [6].

$$\text{Moisture Content (\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

Where w_i is the initial mass of the fish feed; and w_f is the final mass of the oven dried fish feed.

2.3.2. Dimensions. The pelleted feed length and diameter were measured using a digital calliper (Digimatic Series Tokyo, range 0-15 cm ± 0.01 cm). It was presumed that fish feed was cylindrically shaped. Hence, the formula equation (2-5) for volume, surface area, GMD (Geometric Mean Diameter) and sphericity of a cylindrical shape was used to calculate were used.

$$\text{Sphericity (\%)} = \frac{(LW^2)^{\frac{1}{3}}}{L} \times 100 \quad (2)$$

$$\text{Geometric Mean Diameter } D_p \text{ (mm)} = (LW^2)^{0.3333} \quad (3)$$

$$\text{Surface Area (mm}^2\text{)} = 2\pi r\,(r + L) \quad (4)$$

$$\text{Volume (mm}^3\text{)} = 2\pi r^2 L \quad (5)$$

2.3.3. Mass. The mass was measured for 100 randomly selected samples using the analytical weighing balance (A & D, model N92, range 0 – 210 g ± 0.001 g).

2.3.4. Expansion rate. The pellet expansion ratio was measured following [7]. It's expressed as shown in equation. (6).

$$\text{ER (\%)} = \frac{W_p - D_d}{D_d} \quad (6)$$

Where ER is expansion rate, W_p is the Pellet diameter and D_d is the die diameter

2.3.5. True Density. The pellet (randomly selected 50) unit density was measured was measured according to [7–9].

2.3.6. Bulk Density. The bulk density was determined using the method by [8,10]. The bulk density measurement was in three replicates as expressed in equation (7).

$$\text{Bulk Density} = \frac{Mass\ of\ Bulk\ Volume\ (kg)}{Bulk\ Volume\ (m^3)} \quad (7)$$

2.3.7. Porosity. The porosity of a material is associated with the unit density and bulk density of the same material [11].. Therefore, the feed porosity was evaluated using equation (8):

$$\text{Porosity} = 1 - \left[\frac{BD}{UD}\right] \times 100 \quad (8)$$

2.3.8. Colour. The colour pelletized fish feed was measured using the procedure stated by [7] .

2.3.9. Sinking velocity. According to [12,13] technique, the sinking velocity was evaluated. A graduated cylinder of 2 litres was filled up with water. The feed was thrown into water-filled cylinder and the time to travel from the top to the bottom of the cylinder was taken using the stop-watch.

2.3.10. Water Absorption Index (WAI) and Water Solubility Index (WSI). These two physical properties were determined following [7]. WAI shows the volume occupied by starch after the pellets absorbs water while WSI defines the amount of polysaccharides released after adding water [14].

$$WAI = \frac{Mass\ of\ Gel}{Mass\ of\ Sample} \quad (9)$$

$$\text{WSI (\%)} = \frac{Mass\ of\ the\ extracted\ dried\ solid}{Mass\ of\ the\ original\ Sample} \times 100 \quad (10)$$

2.3.11. Water Stability. Water stability was determined by placing the pellets in water and stirred feigning a real aqua cultural conditions using the magnetic stirrer. It is the time taken before the fish feed disintegrate and its measured in minutes [4].

2.3.12. Pellet Durability Index (PDI). It was evaluated using ASAE standard method S269.4 [7]; as displayed by Eq. (9).

$$PDI(\%) = \frac{Ma}{Mb} \times 100 \quad (11)$$

2.4. Thermal Properties

The measurement of the pellets thermal properties was taken using the thermal properties analyser (accumet Model AP75). It determined the feed thermal conductivity and thermal diffusivity. The thermal resistivity was calculated as the reverse thermal conductivity.

2.5. Nutrient and Mineral Composition

The crude carbohydrate, crude fibre, ash, crude fat, crude protein of the fish feed was determined using the AOAC method. The potassium, calcium, phosphorus and zinc content were also analysed using the AOAC method [15].

2.6. Statistical Analysis

All gathered data were evaluated with Microsoft Excel 2016 and SPSS IBM version 22 using a 0.05 Type I error rate (α) by variance assessment (ANOVA) to determine whether there will be important variations between treatments [9,16,17].

3. Results and Discussion

The result of the physical properties and mechanical properties of the pelletized feed are shown in Tables 1 and 2 while that of the thermal properties of the feed is shown in table 2. The nutritional and mineral composition of the pelletized feed is shown in table 3.

3.1. Physical and Mechanical Properties

Table 1 showed the average length, surface area, quantity, geometric mean diameter, sphericity, mass and standard deviation and variation coefficients of fish feed pellets. The mean length (mm) of the fish feed pellets are 19.33 ± 3.23, 14.38 ± 1.32, 15.19 ± 1.80 and the average mass (g) is 0.344 ± 0.1, 0.297 ± 0.44, 0.261 ± 0.036 for P1, P2, and P3, respectively. The average surface area (mm^2) and average volume (mm^3) of the pellets varied from 256.41 to 305.95 mm^2 and 518.98 to 620.45 mm^3, respectively. The average geometric mean diameter (mm) as shown in Table 1 varied from 6.89 to 7.30mm and average sphericity varied from 38.51% to 49.79% for P1, P2, and P3. Table 1 also presented the mean diameter, and its expansion rate. The mean actual diameter (mm) and expansion rate (percent) of the pellets of fish feed are 4.51 ± 0.3, 5.02 ± 0.20, 4.66 ± 0.24 mm and 12.73 ± 7.57, 25.54 ± 5.03, 16.40 ± 6.19% for P1, P2, and P3, respectively. The mean diameter disclosed that pellet feeds from the die of pelletizing machines expanded after being forcibly ejected.

According to [18] the actual diameter and expansion rate of pellet fish feed ranged from 1.51 to 4.55 mm and from 33.31 to 40.94%, respectively. The expansion ratio is a significant variable in aqua feeds as it impacts extrudate floatability [19].

Table 1 also showed the unit density (kg/m^3), bulk density (kg/m^3), and porosity (%) of the fish feed pellet samples. P2 has the highest unit density which was 518.36 kg/m^3, and P1 having the lowest density. P3 had the highest bulk density but the lowest porosity, and it is known that porosity, bulk density and density are interrelated. The bulk density is a significant physical property, when producing feeds in large scale. It affects the handling and storage [20,21]. If the bulk density is higher, it implies that the cost for packaging, transporting and storing will be reduced. Several parameters affect the bulk density of fish feed, for example the expansion rate of a feed affects it bulk density. The expansion rate can be affected by temperature of the pelletizer, pressure of the screw and the feed compositions.

The average water absorption indices WAI and water solubility indices WSI (%) of the feed pellets as shown in Table 2 varied from 2.14 to 2.66 and 11.97 to 16.5% for the WAI and WSI, respectively. While P1 has the highest water absorption indices, it also has the lowest water solubility indices and vice versa for P3. Basically, after swelling in water, WAI can be described as the quantity of occupied volume by the material's starch content. In other words, WAI shows the portion of starch that the extrusion cooking did not affect and preserved its inner structure [7]. On the other side, the water solubility index can be described as the starch part that was transformed during the cooking phase of the extrusion.

The pellet durability index PDI (%) of the fish feed pellets samples were 68.6 ± 2.2, 41.07 ± 1.58, 53.44 ± 1.22% for P1, P2, P3 respectively as shown in Table 2. While the water stability WS (seconds) of the fish feed pellet samples were 27.1.4 ± 5.8, 12.40 ± 0.67, 35.96 ± 4.02 secs for P1, P2, P3 respectively as shown in table 2. According to [22], the fishes used for the research preferred the feed with lower water stability, although it was concluded in the study that feed with higher water stability and high durability index because during packaging there will be reduced abrasion or broken feeds .

The colour of the fish feed pellet samples was lighter than the extrudates sample, in respect to the absorbance measured as shown in table 2. P3 had the deepest colour of all pellets with an average absorbance of 35.93 and P1 had the lightest colour with an average absorbance of 12.43. It was even glaring by visual observation. Colour is a physical property that can be changed during the cooking process of extrusion. According to [23], due to elevated temperatures, Millard reactions and protein denaturing play major roles in colour changes during the cooking process. Reactions happen between decreasing end of carbohydrates and proteins resulting in reduced dietary value darker product. These non-enzymatic browning responses can ruin the protein molecules ' amino acid chains [24,25]. Changes in the colour of extruded products may also be regarded a sign of loss or modification of lysine [26].

3.2. Thermal properties

The thermal properties of the fish feed pellet samples are shown in Table 2. The thermal conductivity of the pellets is 0.3004, 0.3276, 0.3264 W/m.K while the thermal diffusivity is 0.766 x 10-3, 0.749 x 10-3 and 0.798 x 10-3 cm^2/ sec for LMU pellets, P2 and P3 respectively. This similar to the result obtained by [7].

3.3. Nutrient and Mineral Composition

Table 3 shows the crude protein, crude fibre, crude fat, crude carbohydrate, moisture content and ash percentage in each of the selected pelleted feed. The crude protein varied from 31.91 to 42.23%. LMU pellets had 31.91% of crude protein, while P3 had 42.23%. The feed protein content was related with the water stability and durability of the feed. That is, the higher the protein, the more stable and more durable a feed is [27]. The moisture content of the pellets was 14.29, 13.64, 20.00% for LMU pellets, P2, and P3, respectively. Moisture content (MC) is an important factor because it affects overtime shelf life, enzyme activity, vitamins, and food product colour. The smaller the MC, the reduced the spoilage ability. [3,28] found out that moisture content of less than 10% can guarantee a longer shelf life for most food products, P3 was already spoiling after three weeks of production. The crude carbohydrate of the pellets was 35.66±1, 31.93±1, and 10.59±1% for LMU pellets, P2, and P3, respectively. P3 had the highest ash content (11%) and crude fat (15%) content amid the selected pellets, it was also the pellets that displayed spoilage.

In addition, Table 3 discloses the Calcium, Phosphorus, Potassium and Zinc content of the pellets. The Calcium content of the pellets are 4.40, 3.20, 2.96 mmg/g while the phosphorus content of the pellets is 53.34, 26.59, and 27.03 mmg/g.

4. Conclusion

Based on the experimental result, the following conclusions were deduced from the evaluation of the physical properties and mechanical properties of the pelletized feed. LMU pellets had the highest unit density (565.66 $kg.m^{-3}$) due to its length (19.33 mm), WSI (2.66), porosity (74.73%), and PDI (68.60%) but the P2 had the highest expansion rate (25.55%) while P3 had the highest WSI, bulk density, colour amid the selected pellet feeds.

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Table 1. Physical Properties of Pelletized fish feeds

Parameters	P1 Mean	P1 SD	P1 CV	P2 Mean	P2 SD	P2 CV	P3 Mean	P3 SD	P3 CV
Length (mm)	19.3268	3.29972	5.857	14.3822	1.31628	10.926	15.1924	1.8029	8.427
Surface Area (mm^2)	305.9522	52.79613	5.795	266.6824	25.52645	10.447	256.4109	30.65839	8.363
Volume (mm^3)	620.4531	138.6152	4.476	571.1575	74.05505	7.713	518.9841	83.46843	6.218
Geometric Mean Diameter (mm)	7.2976	0.5435	13.427	7.1245	0.3076	23.161	6.8936	0.37214	18.524
Sphericity	0.3851	0.04914	7.837	0.4979	0.03172	15.698	0.4579	0.03836	11.936
Mass (kg)	0.3439	0.09585	3.588	0.2969	0.04376	6.786	0.2606	0.03599	7.24
Actual diameter (mm)	4.5091	12.7275	14.882	5.0218	0.2014	24.94	4.656	0.2479	6.1985
Expansion Rate (%)	12.7275	7.57462	1.68	25.545	5.0348	5.07	16.4	18.779	2.646
Density (kg/m^3)	407.0797	352.95955	0.867	518.3596	73.3044	0.141	511.7408	23.3447	0.046
Bulk Density (kg/m^3)	269.2169	4.49585	0.017	267.3381	4.69709	0.018	271.9358	6.76114	0.025
Porosity (%)	74.73	0.423	0.06	70.49	0.518	0.07	68.45	0.783	0.11
Sinking Velocity (m/s)	0.8445	0.0796	4.657	0.7609	0.0745	4.012	0.8954	0.0814	5.17

SD: Standard Deviation, CV: Coefficient of variation

Table 2. Some physical and thermal properties of the pelletized fish feed

FEED CODE	WAI	WSI	PDI	WS	COLOUR	k (W/m. K)	α cm^2/sec	R (K. m/W)
P1	2.66	11.97±1.2	68.60±2.28	27.14±5.80	12.43±3.40	0.3004	0.766 x 10-3	3.3288
P2	2.18±0.1	13.39±0.6	41.07±1.58	12.4±0.67	25.37±1.70	0.3276	0.749 x 10-3	3.0524
P3	2.14±0.1	16.50±0.3	53.44±1.22	35.96±4.02	35.93±3.65	0.3264	0.798 x 10-3	3.0642

Legend: WAI: Water Absorption Index, **WSI:** Water Solubility Index (%) **PDI:** Pellet Durability Index (%), **WS:** Water Stability (mins), k: thermal conductivity, α: thermal diffusivity, and R: thermal resistivity

Table 3. Evaluation of the Proximate and Mineral Content of the LMU Pellet with two local pelletized feed

SAMPLE CODE	NUTRITIONAL AND MINERAL COMPOSITION									
	Crude Protein	Crude Fibre	Crude Fat	Moisture Content	Ash	Crude Carbohydrate	Calcium	Potassium	Phosphorus	Zinc
P1	31.91±1[a]	1.64±1[a]	8.50±1[a]	14.29±1[a]	8.00±1[a]	35.66±1[c]	4.40±1[a]	1.69±0.1[b]	53.34±1[b]	9.56
P2	33.33±1[a]	2.25±1[a]	11.88±1[b]	13.64±1[a]	6.97±1[a]	31.93±1[b]	3.20±2[a]	1.16±0.02[a]	26.59±0.6[a]	9.85
P3	42.23±1[b]	1.18±1[a]	15.00±1[c]	20.00±1[b]	11.0±0.8[b]	10.59±1[a]	2.96±1[a]	1.63±0.2[b]	27.03±1[a]	9.85

Data are presented as "Mean ± SD". Values with the same superscript letter(s) along the same column are not significantly different ($p<0.05$)