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Influence of Pelletizing Conditions on Fabricated System Performance, Physical and Mechanical Properties of a Cassava Flour Based Fish Feed

Oduntan, Oluwafemi Babatunde[a*], Bamgboye, Adeleke Isaac[b] & Oladimeji, Olumide Joshua[b]

[a]*Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Nigeria.*
[b]*Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.*

**Corresponding author: femkem03@yahoo.co.uk*

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ABSTRACT

Conventional screw press fish pelleting machines are commonly used as a method of producing fish feed, but often affect the product properties. Manual pelletizers using hydraulic press instead of screw in a cassava flour-based diet can be easily processed, which can improve handling and storage. The influence of the pelletization parameters on some properties of cassava-based pellets was the focus of this study. The conditioning factors analyzed were: die size (4, 6 and 8mm), temperature (30, 60 and 90°C), cassava inclusion (5, 10, 15 and 20%) and the influence of the mash moisture content (35, 40 and 45%) on the process and product responses. The quality of the pellets was evaluated in view of current standards. Second-order polynomials were applied to demonstrate the responses as a function of process factors. The studied factors had significant effects on the process response (throughput) and pellet properties (durability and bulk density). Majority of the values of throughput, bulk density and durability of the produced pellets attained the standard limits. Pelletizer operated optimally with processing parameter at 6.0 mm die size, 60°C temperature, 40% moisture content and 20% cassava inclusion rate resulted in pellet temperature (64.4°C), moisture content (34.21%), throughput (932.26 g h^{-1}), bulk density (0.36 g cm^{-1}), durability (99.1%) and hardness (0.30 kN). Pelleted feed using a manual press device under high cassava containment improves the properties of the product. Therefore, the applicability of the response surface method to optimize the process variables is sufficient.

Keywords: Conditioning; Throughput; Product responses; Optimally; Quality

INTRODUCTION

Nigeria has superior natural conditions suitable for aquaculture growth. In the last 30 years of development, Nigeria has become one of the fastest producers and processors of aquaculture products in Africa. Its production value is among the highest in the world. Aquaculture production has become one of the pillar industries of the country's agriculture and youth development plan. Fish feed is the single most important factor in commercial fish production. The quality of the feed has a direct impact on quality production in the aquaculture industry. The feed quality is an important measure to increase the production of the fish industry. It has been reported that feed accounts for approximately 50% of the variable costs of fish production (Kuhn 2017). At present, commercial fish feeds are manufactured as either extruded (floating) or pressure-pelleted (sinking) feeds (Kuhn 2017). These methods have become a significant development and can influence overall technique in processing feed pellets (Amadi 2007). Its numerous advantages, such as the relieving the storage, transportation of feed and improving feed productivity (Kaliyan and Morey 2009).

Pelleting animal feed requires a strong influence of many factors such as feed loading rate, feed composition, moisture, conditioning temperature, point pressure and shape geometry. These ingredients and process factors control the extent of changes during pelletization, which in turn affect the product properties of pellets. The most commonly used feed is mainly made with corn due to its good expansion properties. Conversely, it tends to lower the protein content of the feed due to the high inclusion in the composition while achieving a good pellet quality. Therefore, there is an increasing demand from farmers for well-binding ingredients with low energy production.

Cassava flour has a high starch content (83-87%) (Emmanuel et al. 2012) and a low protein and lipid content (Yadav et al. 2015), which can facilitate a pelletizing and extrusion process for the production of animal feed. In addition, cassava flour is odorless and has an excessive clarity of low stick paste (Adejumo et al. 2011), which makes it a suitable ingredient for pellet development (Santillán-Moreno et al. 2011). Using cassava as an alternative to grains in feed would improve the nutrient density of these feeds because cassava contains more starch. Hence, the expansion of cassava-based fish feed could provide a smart exit for cassava use. However, there is a limit to the amount of cassava flour in pelleted fish feed.

At overseas, Rosentrater et al. (2009) examined in detail the effect of ingredients and extrusion parameters on the properties of aquatic feed containing dried distillatory grains with soluble substances (DDGS) and corn starch. Ryu and Ng (2001) carried out an analysis of the effect of selected processes on the expansion and mechanical properties of wheat flour and corn flour extrudates. Yadav et al. (2015); Meng et al. (2010); Ding et al. (2006) reported that the bulk density decreased with increasing cassava content. It has been shown that the throughput correlates well with the feed properties such as density and durability (Rosentrater et al. 2009; Bandyopadhyay and Rout 2001; Rolfe et al. 2001; Shukla et al. 2005; Colonna et al. 1989). In Nigeria, Oduntan et al. (2012) studied the performance evaluation of a cassava flour performed on a motorized pelletizer. Ojomo et al. (2010) examined ingredients, some of them on the pelletizer at varied processing conditions. In addition, Adesina and Bolaji (2013) are based on the effect of milling machines and sieve sizes on the quality of cooked cassava flour.

The analysis of the research status at home and abroad revealed that the processing conditions affect the performance of the machines. It has also been found that most pelletizing machines are motor-driven and are powered by electric motors or gasoline engines. The motor-driven pelletizer is effective for the commercial production of fish feed. The lack of a constant power supply and the high fuel costs for the generator add to the cost of fish feed production, causing a major setback in the industry. Therefore, based on the existing manual pelletizing machine, the optimal design experiment was applied to build a model for machine performance, analyze the correlation between the operating conditions of the machine and its performance through regression variance and response surface, and provide an optimization of the pelletizer for the production of fish feed.

MATERIALS AND METHODS

DESCRIPTION AND OPERATION OF THE MACHINE

The manually operated aquafeed pelletizer (Figure 1) is basically a combination of hydraulic jack and die. The pelletizer consists of; a galvanized H-channel or frame, a 5-ton hydraulic jack, cylinder with die, pellet tray and compression plate welded to the top of frame. The Hydraulic jack is welded to the base of a rectangular frame to raise a tray upward. The tray is designed to house the die. The die is an open-end cylinder, with perforations on its surface area. The compression plate serves as a back plate for retaining the pressure exerted by the hydraulic jack on the cylinder, whilst the perforations in the die allow the compressed mash wriggle out to form pellets. The die is to simulate the pellets by using holes (4, 6 and 8 mm) in real scale.

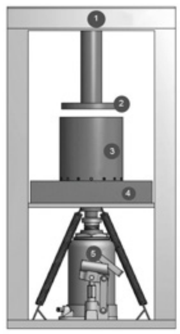

FIGURE 1. Labelled Sectional Elevation of the Manually Operated Pelletizer: 1- Frame, 2- Feed Compression Plate, 3- Cylinder/Die, 4- Pellet Tray, 5- Hydraulic Jack.

TABLE 1. Feed formulation utilized for the trial

Feed Ingredients	Mass of ingredients (%)				
	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
Soya bean meal	39.7	39.7	39.7	39.7	39.7
Groundnut cake	10	10	10	10	10
Fish meal	22	22	22	22	22
Wheat offal	5	5	5	5	5
Corn flour	20	15	10	5	-
Cassava flour	-	5	10	15	20
Di-calcium phosphate	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Lysine	0.1	0.1	0.1	0.1	0.1
Methionine	0.1	0.1	0.1	0.1	0.1
Vitamin	0.1	0.1	0.1	0.1	0.1
Fish oil	1.5	1.5	1.5	1.5	1.5
Premix	0.5	0.5	0.5	0.5	0.5

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Proximate Analysis					
Crude protein	43.69	43.87	44.79	43.37	42.88
Ash	9.65	9.71	9.74	9.59	9.48
Crude fiber	3.27	3.34	3.38	3.21	3.17
Crude fat	4.65	4.72	4.87	4.68	4.55
Moisture content	9.05	8.89	8.08	9.22	9.22
Nitrogen free extract	29.69	29.47	29.12	29.93	30.65

The fish feed ingredients were purchased from a local market in Ibadan, Nigeria. The feed formulation was carried out, by varying the inclusion rate of cassava over five formulations (Table 1). The feed ingredients were ground to obtain an even particle size distribution. The formulated feed was conditioned by adding a calculated amount of water at varying temperature to the sample, to raise the moisture content from the initial value to the required level of 35, 40 and 45% (w.b.) (Oduntan et al. 2015). The feed compositions were conditioned at different temperature ranges (30, 60 and 90°C) before introduced to the cylinder, which was then fitted on top of the tray. The hydraulic jack pushes the cylinder upward, while the stationary compression plate builds up pressure for the extrusion of the feed. Increased pressure, forces the mash through the perforations in the die, compressing it and forming it into pellets.

SAMPLING AND DETERMINATION OF PROCESS RESPONSES

The pellets were allowed to break off by gravity, but excessively long particles were break easily during handling. The pelleting process was carried out in triplicate. The products temperature was measured using infrared thermometer (MT-18A, Bengal, India). The pellet formed was collected, weighed and mean values recorded. Pellet samples were sun dried (thin film drying) for 4 hours to remove excess moisture that could spoil the pellets and were packed in airtight plastic containers until measurements were taken. The moisture content of all samples was determined with a halogen moisture analyzer.

The manually operated machine throughput was calculated according to the method developed by Oduntan *et al.* (2014), for each sample in three replications. In brief, weight of pelletized feed samples was determined for the time taken to complete the process. The throughput was calculated as:

$$M_{Tpt} = M_p / T \quad (1)$$

where:
M_p – mass of the pellets collected (kg)
T – process time (h)

DESIGN OF THE EXPERIMENT

The study was carried out using the response surface methodology on the effects of manually operated pelletizing conditions on the process and product responses of the fish feed based on cassava flour. The results of the preliminary studies were used to determine suitable machine operating variables. The independent variables considered for this study were die size (4-8mm), temperature (30-90°C) and cassava inclusion rate (5-20%) at the moisture content of the mash (35-45%). A flexible optimum design structures to accommodate the model, categories factors and irregular regions was employed to determine the pelleting conditions (Table 2). The studies were randomized to reduce the bias in the observed responses due to unrelated factors.

TABLE 2. Experimental design for the experiments

Run	Coded values				Actual values			
	X_1	X_2	X_3	X_4	Cassava inclusion rate (%)	Die size (mm)	Conditioning temperature (°C)	Moisture content (%)
1	-1	0	0	1	0	6	60	45
2	1	0	0	1	20	6	60	45
3	1	-1	0	0	20	4	60	40
4	1	-1	1	-1	20	4	90	35
5	1	0	1	-1	20	6	90	35
6	-0.5	-1	0	1	5	4	60	45
7	1	0	-1	0	20	6	30	40
8	0	-1	-1	1	10	4	30	45

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9	0.5	1	1	-1	15	8	90	35
10	1	1	1	-1	20	8	90	35
11	0.5	0	-1	1	15	6	30	45
12	-1	-1	0	1	0	4	60	45
13	1	-1	-1	1	20	4	30	45
14	0	0	1	-1	10	6	90	35
15	0	0	0	1	10	6	60	45
16	-1	0	-1	0	0	6	30	40
17	0	1	0	0	10	8	60	40
18	-0.5	0	1	-1	5	6	90	35
19	0	-1	0	0	10	4	60	40
20	-1	-1	1	-1	0	4	90	35
21	-1	1	1	-1	0	8	90	35
22	-0.5	1	-1	0	5	8	30	40
23	-1	-1	0	0	0	4	60	40
24	-1	-1	0	0	0	4	60	40
25	1	1	0	0	20	8	60	40

QUALITY ASSESSMENTS OF THE PELLETS

The durability (Du) of the pellets was determined according to ASABE S269.5 (ASABE, 2003). A 100 g sample of the pellet was tumbled at 50 rpm for 10 min in a dust tight enclose. Sieves with 5, 8, and 11 mm apertures were used respectively for the pellets formed from the 6, 9 and 12 mm dies. The test was triplicated to ensure accuracy. Durability was expressed as the percent ratio of the mass of pellets retained on the sieve after tumbling (M_{pa}) to mass of pellet before tumbling (M_{pb}). Durability is said to be high when the measured value is above 80%, medium when between 70 and 80% and low when below 70% (Oduntan et al. 2015).

$$D_u = \frac{M_{pa}}{M_{pb}} * 100\% \quad (2)$$

Bulk density of the pellet was determined as recommended by ASABE S269.4 (ASABE, 2003). A container was filled using a funnel, without compacting the content. The material was levelled with the top surface of the container and weighed. Pellet and flour bulk densities were obtained from the ratios of the measured masses of samples in the container to the volume of the container. Five measurements of each experimental run were taken to obtain the average values and standard deviations. Bulk density is an important parameter in the design of systems for drying, ventilation and cooling of pellets during storage (Fasina and Sokhansanj 1995).

The pelleting efficiency was calculated by the following procedure:

$$\eta_P = \frac{Wa}{Wo} \times 100\% \quad (3)$$

Where:
W_a _ quantity of actual pelleted feed obtained at the die orifice (g)
W_o= Original weight of feed imputed (g)
η_P _ efficiency of the machine. (Ojomo et al. 2010)

The pellet samples were conditioned at room temperature (27°C) for 48 hours in the laboratory and wrapped in polyethylene sealing bags for the tests. An Instron Universal Testing Machine, Model 1122 (Instron Corporation, Canton, MA) was used to apply pressure to 10 mm length of the cylindrical pellets to 50% in the axial direction (Ryu and Ng, 2001). A device was used to ensure that the cut surfaces of the samples were parallel to each other and perpendicular to the longitudinal axis of the samples at a crosshead speed of 10 mm / min. The experiment was repeated five times and the average pressure modulus was determined.

STATISTICAL ANALYSIS

The statistical analysis of the collected data was carried out with Design Expert 11.0. Design –Expert offers comparative tests, screening, characterization, optimization, robust parameter design and modelling the designs. The data obtained was analyzed using analysis of variance (ANOVA) at $\alpha_{0.05}$ to assess differences and determine the significance of the experimental model. Contour model graphs and 3D model graphs were also used to analyze the interaction between the independent variables as they affect the dependent variables or the result of the analysis. A numerical optimization of the data was carried out in order to determine the optimal operating state of the pelletizer. Analysis of the predicted model was performed to locate pelletizing conditions where the fish feed would have maximum throughput and durability, as well as a minimum hardness and bulk density.

RESULTS AND DISCUSION

The effects of pelleting conditions on the machine parameters and product responses are shown in Table 3. The pellets with different properties from the manually operated machine produced were obtained under various processing conditions (Table 3). Results of the regression analysis are shown in Table 4. The regression models for product temperature, moisture content, bulk density and hardness were highly significant ($P < 0.001$) with a high coefficient of determination ($R^2 = 0.99$, 0.83, 0.80 and 0.88 respectively). While a moderately lower R^2 was observed for durability (0.690 and throughput (0.78), regression models were significant ($P < 0.001$). In addition, all models showed a nonsignificant lack of fit ($P > 0.05$), indicating that all second order polynomial models correlated well with the measured data and were statistically significant ($P < 0.05$). The fit statistics (adjusted and predicted R^2) for the variables were in reasonable agreement with each other with adequate precision greater than four. The standard errors observed were similar to each other with lower values resulting in a balanced design.

A summary of the response of the machine processing parameters at various treatments is shown in Table 1.

TABLE 3. Response of processing parameters and pelleted fish feed

Process responses			Products responses		
Pellets temperature (°C)	Pellet moisture content (%)	Throughput (g/hr)	Bulk density (g/cm3)	Durability (%)	Hardness (kN)
67.30	39.04	1180.73	0.44	93.64	0.18
63.80	38.96	1073.91	0.43	95.96	0.37
65.60	33.61	767.75	0.37	92.32	0.43
97.50	28.56	693.31	0.52	96.86	0.47
94.40	26.81	693.31	0.49	98.20	0.41
66.50	38.81	1315.09	0.37	76.35	0.19
33.00	33.83	667.75	0.48	69.51	0.37
34.80	38.48	1007.18	0.33	54.19	0.21
93.50	29.62	695.38	0.56	91.50	0.41
92.10	28.89	693.31	0.49	97.38	0.40
34.30	38.39	633.45	0.29	50.00	0.31
69.30	38.41	1180.73	0.47	98.33	0.16
35.20	38.53	973.91	0.37	83.17	0.42
95.70	29.09	721.00	0.45	96.76	0.42
65.10	39.64	1207.18	0.24	74.86	0.40
36.30	34.24	874.00	0.37	85.00	0.18
62.00	34.05	898.25	0.33	72.76	0.38
96.80	29.27	702.77	0.55	93.88	0.22
66.40	34.54	698.25	0.37	86.73	0.28
99.40	37.36	699.08	0.50	96.15	0.21
94.70	29.38	699.08	0.61	94.71	0.19
33.70	34.51	878.00	0.33	73.45	0.19
68.30	33.38	974.00	0.46	95.63	0.18
67.20	33.39	1270.00	0.42	71.33	0.19
62.80	34.11	967.75	0.48	84.92	0.35

TABLE 4. Regression coefficients of second-order polynomials

Coefficient	Pellets temperature (°C)	Pellets moisture content (%)	Throughput (g/hr)	Bulk density (g/cm3)	Durability (%)	Hardness (kN)
x_0	+64.56	+8.95	+835.17	+0.3509	+78.55	+0.3155
Linear						
x_1	-1.33***	-0.0416	-61.49	-0.0029	+0.0527	+0.1079***
x_2	-1.59***	+0.3327*	-14.09	+0.0035	-2.89	-0.0021
x_3	+30.74***	+0.1000	+179.18	+0.0658*	+18.38***	+0.0671*
x_4	+0.3286	+0.0689	+283.00	-0.0331*	+0.6897	+0.0274
Interaction						
x_{12}	-0.0696		+29.23	+0.0058	-2.87	-0.0196
x_{13}	-0.0724		+70.34	-0.0471	+4.42	-0.0040
x_{14}	-0.2175		+29.00	-0.0199	+4.15	-0.0109
x_{23}	-0.7574		+25.26	+0.0019	-2.89	+0.0668
x_{24}	-0.0214		-11.72	-0.0312	-7.01	+0.0799
x_{34}	-0.5160		+195.26	+0.0405	+13.69	+0.0699
Quadratic						
x_{11}	+0.7657		+32.94	+0.0815**	+11.98*	-0.0405
x_{22}	-0.1974		+57.76	-0.0010	-2.60	+0.0188
x_{33}	+0.0601		+102.64	+0.0553	+6.50	+0.0597
x_{44}	+0.0000		+0.0000	+0.0000	+0.0000	+0.0000
R^2	0.9995	0.8352	0.8032	0.8327	0.6866	0.8810
Adjusted R^2	0.9990	0.8202	0.5707	0.6350	0.5387	0.7405
Adeq. Precision	0.9958	17.3512	6.2087	7.6117	6.5249	8.5504
Lack of fit	5.45	61290	1.766E+05	0.0319	667.43	0.0321

* Significant at P < 0.05. ** Significant at P < 0.01. *** Significant at P < 0.001

QUALITY ATTRIBUTE OF THE PELLET

The pellet temperature was rated in the range between 33.0 and 99.4 °C, which was slightly higher than the conditioning temperatures of the pelletizer (Table 3). This was predictable because heat was generated by viscous dissipation of mechanical energy during the press, causing the pellet temperature to rise. The predicted response model (Table 4) indicated that linear effects of cassava inclusion, die size and temperature variables and quadratic effect of cassava inclusion rate were the fundamental establishing factors for pellet temperature, and there was significant interaction between the die size and temperature. Of the four factors, feed moisture content had the least influence on pellet temperature. The Model F-value of 4892.40 implies the model is significant. The graphs of the response surface plot (Figure 2) showed that an increased cylinder temperature led to an increase in the pellet temperature. However, an increased die size causes the pellet temperature to decrease. High pellet temperature was examined at high die size and cylinder temperature.

The dependence of the shear on the die diameter is known during experimentation. A smaller die size generates a greater amount of frictional heat, which steers to an increase in pellet temperature. As shown in Figure 2a, increasing the die size from 4 to 8 mm decreased the pellet temperature slightly by 3.3°C with 20% cassava inclusion and 40% moisture content. Figure 2b shows the increase in pellet temperature with a reduced cassava inclusion rate.

These results were likely associated with increased temperature of pellet as described in past pelleting/feeding research (Cutlip et al. 2008; Meng et al. 2010; Lilly et al. 2011) The product temperature or the pelleting temperature plays an important role in changing the physicochemical and mechanical properties of the pelleted products, which influence the degree of flow of the mash. Additionally, the gelatinization of starch reduces the temperature in the cylinder as cassava inclusion increases, and increasing the die size decreases mechanical energy dissipation (Oduntan and Koya 2015).

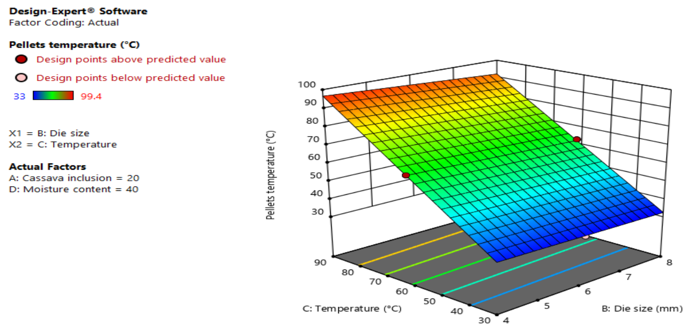

FIGURE 2A. Effect of die size and conditioning temperature on pellet temperature at 20% cassava inclusion.

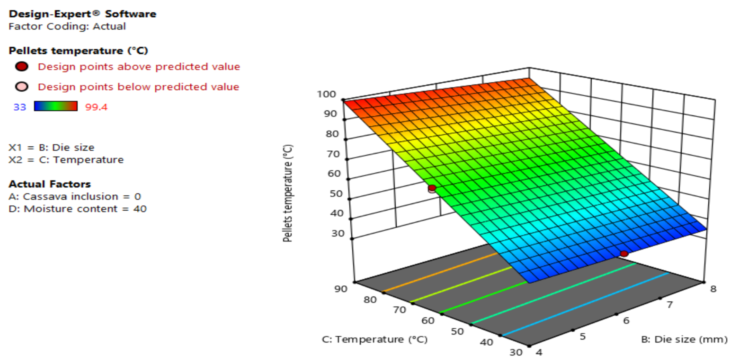

FIGURE 2B. Effect of die size and conditioning temperature on pellet temperature at 0% cassava inclusion.

The pellet moisture content ranges from 8.26 to 9.64% with a ratio of maximum to minimum values of 1.17. The lowest pellet moisture content was obtained for the samples obtained with cassava inclusion (0%), die size (4 mm) and maximum conditioning temperature (90°C) with 35% moisture content, while the highest pellet moisture content f=or the samples was obtained with 10% cassava flour and moisture content (45%) and 60°C temperature with 6 mm die size. The regression analysis showed that the pellet moisture content was significantly influenced by the linear ($p < 0.0001$) effect of the die size and the quadratic ($p < 0.05$) effect of cassava inclusion on the pellet moisture content (Table 4). Figure 3 shows the effect of cassava inclusion and the die size on the pellet moisture content. The result showed that the moisture content of the pellet increased linearly as the size of the pellet increased from 4 to 8 mm, and increased with the increase in cassava inclusion at a certain level and then slightly decreased. A quadratic relationship was observed between the moisture content of the pellet and the inclusion of cassava. This was evident as the heat and pressure generated in the smaller die size are higher, which reduces the moisture content of the mash. These results agreed with Oduntan et al. (2012). According to Case et al. (1992) due to the progress of gelatinization with increasing amount of cassava from cornmeal, resulting in a decrease in pellet moisture content, which is consistent with our observations.

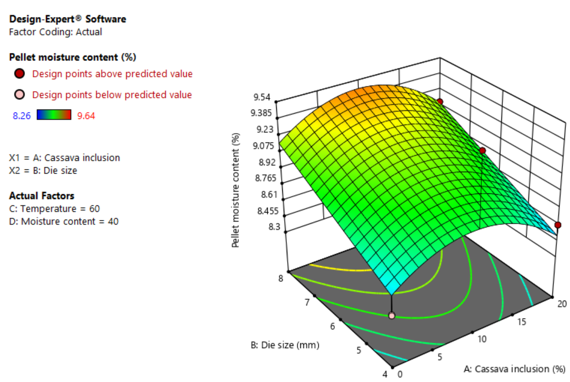

FIGURE 3. Effect of cassava inclusion and die size on pellet moisture content at temperature of 60°C machine throughput

Table 3 show the diet contained 15% cassava with 5% corn flour and operated under processing conditions of 6 mm die size, 30°C temperature and 45% moisture content of the diet mash, the throughput was at a minimum value of 633.45 g/h. Under processing conditions (4mm die size, 60°C temperature and moisture content) a maximum throughput of 1315.09 g/h was achieved. The regression analysis results (Table 4) show a positive effect of cassava inclusion rate (p <0.001), supported by negative effects of temperature, moisture content, and the interaction of temperature and moisture content on throughput (p<0.05). Figures 4 illustrate the response surface plots between temperature and moisture content at levels of cassava inclusion indicated that throughput decreased with increasing moisture content. This can be attributed to increase in backflow of the mash due to the reduced melt viscosity with increasing moisture content, as mash moisture is an important processing parameter in machine performance (Abioye et al. 2018; Senanayake and Clarke, 1999). The interaction effect of temperature on throughput was evident when the cylinder processing temperature was high at 70-90°C with maximum moisture content, but the effect was small when the system was operated at low temperature. Figure 4a shows a large optimal range of interaction performance shown with a low cassava inclusion (less than 5%) compared to the maximum cassava inclusion (20%) in Figure 4b, where there was little room for an optimal area. Throughput was obtained at low cassava inclusion, high moisture and temperature combination. Related results have been described (Oduntan and Bamgboye 2019).

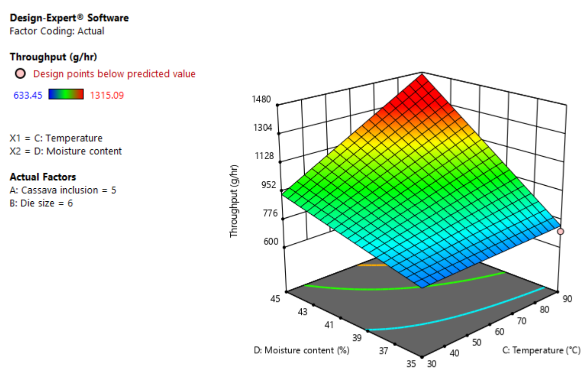

FIGURE 4A. Effect of cylinder temperature and moisture content on throughput at 5% cassava inclusion.

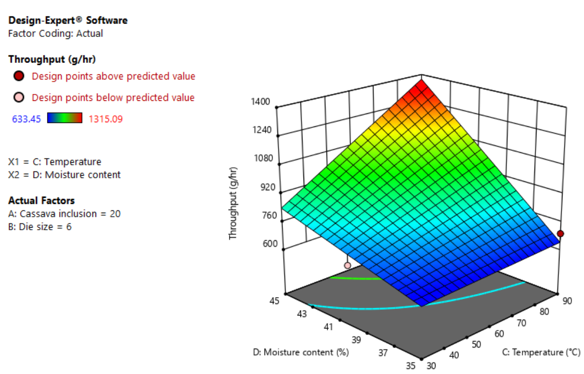

FIGURE 4B. Effect of cylinder temperature and moisture content on throughput at 20% cassava inclusion.

The bulk density of the pellet was in the range from 0.24 to 0.61 g/cm³ (Table 3), comparable to those used for red gunseng with density values of 0.31 to 0.64 g/cm³ (Gui et al. 2012) and commercially available fish feed products (0.27–0.71 g / cm³; Khater et al. 2014). The bulk density with a maximum to minimum ratio of 2.54 showed that an experimental transformation with a ratio of less than 3 has little effect. Bulk density was significantly affected by the linear ($P < 0.05$) and quadratic ($P < 0.01$) effects of temperature, moisture content, and cassava inclusion (Table 4). The response surface plots (Figure 5) showed that product bulk density increased with increasing feed moisture, whereas decreased with increasing screw speed and conditioning temperature. The density of the pellets varied between 0.43 and 0.58 g/cm³. Minimum bulk density, an attractive feature of fish diet products, was obtained with high cassava inclusion and low processing temperature (Figure 5). The interaction analysis predicted that the minimum bulk density (0.45 g/cm³) was obtained at 35% feed moisture content, 10% cassava inclusion, 6 mm die size and 90°C temperature. Similar results were obtained by Sacchetti et al. (2004); Hagenimana et al. (2006) and Filli et al. (2012) that due to the increasing gelatinization of the mash with increasing cassava inclusion during processing, the product volume increases and the bulk density decreases.

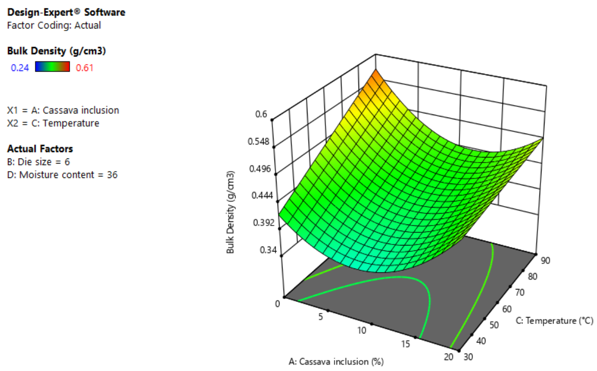

FIGURE 5. Effect of cassava inclusion and temperature on pellet bulk density at moisture content of 35%

The maximum durability of 98.33% was recorded at 45% moisture content using a 4 mm die, while the lowest was 50% using the 6 mm die (Table 4). It was found that the binding forces in small pellets increased the bond between individual particles in the pellet. Similarly, the durability of the pellets increased with conditioning temperature and decreased with die size, indicating that the larger pellets crumbled more easily than the smaller ones during handling. In addition, when a smaller hole size (4mm) is made in the cylinder, the higher amount of heat is generated due to the tighter frictional resistance. This must have led to increased starch gelatinization in the pellet, which holds the particles more tightly together. The statistical analysis showed that the conditioning temperature was significantly influenced by the linear ($p<0.0001$) and the quadratic ($p <0.05$) effect of cassava inclusion on pellet durability (Table 5). A typical 3-D curve of the variation in the durability of pellets with cassava inclusions and the die size at the various conditioning temperatures is shown in Figure 6. Pellet products with cassava inclusion and high temperature pelletization showed a higher degree of gelatinization and durability was maintained by increasing the conditioning temperature with high inclusion of cassava and cornmeal in the diet (Figure 6), which could be attributed to the gelatinization of starch at high processing temperature (Chiu and Solarek 2009). The lowest durability values were observed for the same mixture of cassava and cornmeal at different conditioning temperatures. Increasing the feed conditioning temperatures resulted in increased durability, while die size and humidity showed no significant difference (Figure 6). This could be due to similarities in the properties of cassava and cornmeal.

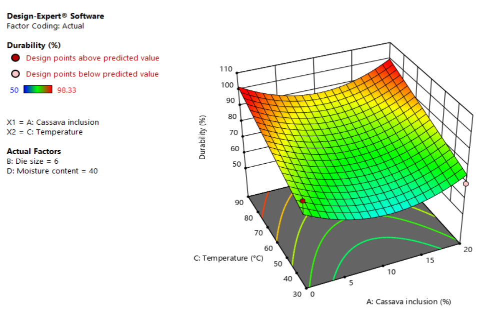

FIGURE 6. Effect of cassava inclusion and temperature on pellet durability

As shown in Table 4, the hardness of fish feed pellets increased from 0.16 to 0.47 kN with a ratio of maximum to minimum value of 2.87. From Table 5, the hardness of the pellets was significantly ($P <0.001$) influenced by the linear effects of the cassava inclusion ($p <0.001$) and the conditioning temperature ($p <0.05$). The maximum hardness was found for the pellet developed at 20% cassava, 4 mm, 90°C temperature with 35% moisture content, while the minimum hardness was observed for pellets developed at 0% cassava, 4 mm, 60°C Temperature and 45% moisture were developed. The lower hardness values favour the properties of pellets. Response surface plots (Figure 7) showed that hardness decreased with decreasing inclusion of cassava and decreasing conditioning temperature. A low hardness value, which is also a preferred property of pellets (Altan et al. 2008; Meng et al. 2010), has been observed at low cassava containment and conditioning temperatures. The results showed that the pellet hardness increased from 0.22 to 0.43 kN when the cassava inclusion increased from 5 to 20%. The breaking strength increased with increasing inclusion of cassava, especially at high conditioning temperatures. With high cassava inclusion, the degree of expansion and the cell wall thickness can be high. The results showed that the minimum hardness (0.18 kN) was predicted at 0% cassava inclusion and 30 ° C conditioning temperature. This is similar to that of grain-based pellets for fish feed (Choudhury and Gautam 2003; Jeyakumari and Rathnakumar 2006).

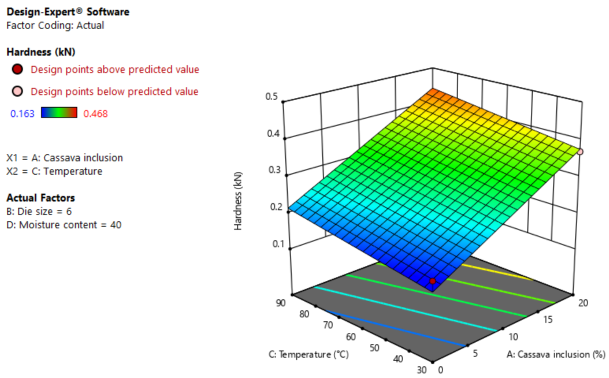

FIGURE 7. Effect of cassava inclusion and temperature on hardness

OPTIMIZATION OF PELLET PROCESS PARAMETERS

In order to optimize all results with different goals, a decision approach with several criteria such as a numerical optimization technique through the desirability function and a graphic optimization technique through the overlay diagram were used (Figure 8). The optimized operation was obtained by applying constraints to the response. From the range investigated, the product temperature of 50-80°C was chosen as the optimum, with the high temperature leading to the denaturation of vitamins and the low temperature leading to high particle formation due to the poor binding efficiency. A pellet moisture content of 9-10% was selected as suitable because of the good shelf life and improved coating efficiency. The throughput of 633 - 1400 g/h was selected as a suitable device capacity in order to keep production and the shaft speed constant. Due to the size of the packaging, a bulk density of 0.425 g/cm³ was chosen as optimal. A durability of 70-100% was chosen due to handling, and too short a durability leads to poor products with high particles. The minimum hardness value of was chosen based on the digestibility rates of fish for optimal performance. From the overlay contour (Figure 9) by adding confidence interval to the selected criteria. The robustness of the design space was kept away from the edges. The yellow area showed a consistently good conditions for the production of the pellets. The results obtained from the processing condition performed with optimized process variables were 6.0 mm die size, 60°C temperature, 40% moisture content and 20% cassava inclusion rate, resulting in pellet temperature (64.4°C), moisture content (34.21%), throughput (932.26 g h^{-1}), bulk density (0.36 g cm^{-1}), durability (99.1%) and hardness (0.30 kN). The overall desirability, ranging from zero out of bounds to one on target, was 0.834.

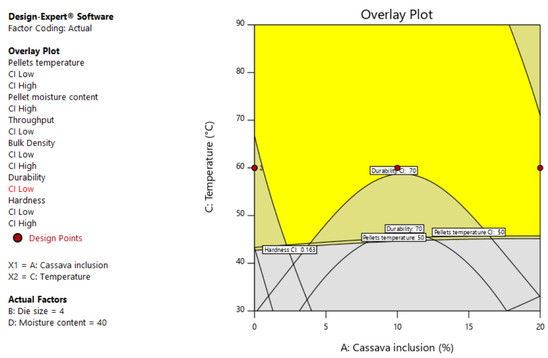

FIGURE 8. Overlay contour for optimization of the processing condition

CONCLUSIONS

Pelletized feed delivery systems are a promising form of waste reduction that could be a better alternative to traditional dosage forms to reduce bulkiness by increasing fish performance while achieving superior feed efficiency. Cassava-based feed delivery is a potential approach to solving inappropriate particle sizes and separating ingredients by gelatinizing at high temperature. A systematic study using the response surface method revealed that the factors examined had significant effects on process behavior (throughput) and pellet properties (durability and bulk density), which are the most important parameters for pellet production. The majority of the values for throughput, bulk density and durability of the pellets produced reached the standard limits. The pelletizer worked optimally with processing parameters at 6.0 mm die size, 60°C temperature, 40% moisture content and 20% cassava inclusion rate, resulting in pellet temperature (64.4°C), moisture content (34.21%), throughput (932.26 g h^{-1}), bulk density (0.36 g cm^{-1}), durability (99.1%) and hardness (0.30 kN). Therefore, the applicability of the response surface method to optimize the process variables in the manufacture of a manually operated pellet system is sufficient.

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DECLARATION OF COMPETING INTEREST

None

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