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Research Article

Performance Evaluation of a Locally Developed Single Screw Floating Fish Feed Extruder

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Abstract

The locally developed floating fish feed extruder was evaluated for performance in terms of machine parameters such as; screw speeds (158.5, 225 and 334 rpm), die size (4, 6 and 8 mm) and moisture content of feed materials (20, 30, 40 and 50%), on specific mechanical energy requirements, expansion ratio, bulk density and pelleting efficiency were determined. The research results showed that increasing the screw speed from 158.5 to 225 rpm incline to increase extrusion efficiency from 64 % to 68 %, decrease in bulk density from 1.05 to 0.95 g/cm^3; decrease in specific mechanical energy from 26.40 to 24.20 kj/kg. By enlarging the die size from 3 mm to 5 mm, the specific mechanical energy incline to reduce from 28.40 to 26.60 kJ/kg, reduce bulk density from 1.05 to 0.95 g/cm^3, increase extrusion efficiency from 64.00 to 68.00%. Increase in moisture content from 20 % to 30 % tend to reduce the specific mechanical energy from 28.40 to 26.60 kj/kg, reduce bulk density from 1.05 to 1.00 g/cm^3, and increase the extrusion efficiency from 64.00 to 72.00 %.

Keywords: Extruder; Mixer; Fish Feed; Floating; Performance; Temperature.

Introduction

The extrusion process operates in a dynamic steady equilibrium where input variables are balanced with the output. Fish feed requirements is vary in quality and quantity according to their feeding habits and digestive anatomy as well as their size and reproductive state. Feed requirements are also affected by environmental variations such as temperature and the amount and type of natural food available [5]. Availability of high quality fish feed is one of the greatest problems that affects the expansion of the small scale fish industries in Nigeria [5].

It requires high quality nutritionally balanced diet for growth and attainment of table size within the shortest possible time. Therefore local production of fish feed is very crucial to the development and sustainability of aquaculture in Africa especially, in Nigeria rural areas [6] and this is expected to replace the present dependence on foreign feeds. Fish feeds could be of two type's vis. Floating fish feed and sinking fish feeds and these are obtained based on production processes and feed components.

According to [12], process parameters like the type of extruder, length of barrel, feed rate, speed, screw configuration; moisture content and so on can also be attributed to the system parameters. System parameter are type of extruder, length of barrel, feed rate, screw speed, moisture content, screw configuration etc. and momentum transfer parameters are; viscosity, torque, specific mechanical energy (SME), extrusion pressure, and mass flow rate etc and thus to optimize and scale up the process appropriately [1]. The product temperature, which affects the degree of cook and melts rheology, is determined by the temperature profile of the barrel. Product quality attributes are also affected by the induce reaction of the intermediate process parameters like the screw speed, die geometry, barrel temperature among others [7].

Materials and methods

System Parameter

Product Temperature

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The temperature of the product was determined as described by [2]. This parameter was measured with Temperature data logger which was designed and locally fabricated at the Electronics laboratory of the Physics Department Fut-akure, was inserted into the barrel. This represents the thermal energy.

Specific Mechanical Energy Requirement (SME)

This is a measure of the work done by the extruder on the feed materials; the energy that is transformed into the thermal energy; an important index in terms of the cost of manufacturing extruded products. SME according to [8], it was calculated using the equation below:

$$SME = \frac{2\pi \times \tau \times \frac{ss}{60}}{Fr} \times 3.6 \left(\frac{Kj}{Kg}\right) \quad (1)$$

Where; τ is the corrected torque (Nm), s_s is the screw speed (rpm), F_r is the feed rate (Kg/h). The torque required to drive the screw was calculated according to [10] using the equation below:

$$\tau = \frac{60P}{2\pi N} \quad (2)$$

And

$$P = \frac{P_{th}}{\eta} \quad (3)$$

Where, P = input power, η = extruder efficiency, P_{th} = theoretical power required by the extruder, N= machine speed in rpm, T= torque required.

Extruder Efficiency

The extruder efficiency was evaluated by determining parameters like the extrusion capacity and functional/extrusion efficiency of the machine from the observed data. Extrusion capacity was calculated according to [8] using the equation below:

$$EC = \frac{M_e}{T} \quad (4)$$

Where; EC= extrusion capacity (Kg/min), Me = mean mass of the extrudates for each treatment (Kg), T= mean time taken for the extrusion (min).

Extrusion/functional efficiency were calculated as the ratios in percentage of the extrudates to the initial mass of materials fed into the machine. This is represented mathematically as:

$$RE = \frac{M_e}{M_i} \quad (5)$$

Where; RE= extrusion efficiency (%), Me = mean mass of extrudates (Kg), M_i= mean initial mass of ingredients (kg) [8]

Product Parameters

Product Moisture Content

The moisture contents of the extruded feed were determined on dry basis by an oven drying method. About 10 g of each sample were dried in an oven at about 100 ± 2°C for about 18 hours. A Philip Essence HR 2394 measuring balance made in Hungry was used in weighing the extrudates before and after the drying and allowed to cool in a desiccators to determine the loss in weight which also represents moisture loss. Pictorial view of Extruder Machine is shown in Figure 1. Extrusion of the extrudates is shown in Figure 2.

Figure 1. Pictorial view of Extruder Machine

Figure 2. Showing extrusion of the extrudates

Expansion Ratio

This was determined according to [4] were extrudates are measured using Vernier caliper and the radial expansion ratio calculated from the formula below:

$$Er = \frac{D^2}{d^2} \quad (6)$$

Where; Er = expansion ratio, D = extrudates diameter and d = diameter of the die.

Experimental Plan

This experiments was conducted using a factorial design comprising of three levels of initial moisture content, three levels of screw speed and three levels of die size which were replicated three times. The three independent variable levels were pre-selected based on the results of the preliminary tests

Test Parameters

The performance criteria considered are the product temperature, Specific Mechanical Energy (SME), expansion ratio, torque. The performance variables include the constant variables (screw configuration and feed rate) while the running variables are described below:

- Four levels of initial moisture content; 20 %, 30 %, 40 % and 50 % (d.b).
- Three levels of screw speed; 158.5 rpm, 225 rpm and 334 rpm.
- Three levels of die sizes; 4 mm, 6 mm and 8 mm.

A formulation was used so as to know the effect of various running variables on the product quality characterization of the extrudates. Three replicates were carried out for each treatment; statistical tests were conducted using Microsoft Excel (2010). Graphical plots and diagrammatic representations were also generated using the aforementioned tool.

Sample Preparation

Cassava starch was used to replace the GNC – Groundnut cake because of it lighter density to function as the binder, other materials with lesser bulk densities compared to that of water were sources locally and powdered to enhance higher degree of compactivity during extrusion. These various products were gotten from Cossy Feed Mill, Ibadan way; Kainji, New Bussa, Niger state, Nigeria except the Cassava (*Manihot esculenta Crantz*) TMS 30572 that was gotten from experimental plots at the Federal College of Agriculture, Akure and processed into flour. The materials were prepared and processed by the standard recommended by Nigerian Institute for Oceanography and Marine Research (NIOMR).

The experimental ration used was in the composition as shown below; the mixing was done manually as a result of the lack of required machine that could be used. The moisture content of the ration was determined on a dry basis by placing about 20g of the mixed ration was placed in an oven at about 100 ± 2°C for about 18 hours. The dried sample was then reweighted to determine the moisture loss from the weight loss.

Table 1. Ingredient components of the feed blend used (%) (NIOMR, 2016)

Feedingredients	(%)
Cassava meal	39
Soya bean meal	40
Fish meal	20
Fish premix	0.5
Vitamin C	0.1
Antioxidant (antimold)	0.4
Sum (%)	100

Result and discussion

Effect of Extrusion Variables

Two system parameters namely: temperature & Specific Mechanical Energy; and two product parameters namely: product moisture content & expansion ratio were used. The results are discussed as follows:

Effect of Extrusion Variables on System Parameters

The system parameters studied includes the product temperature and the specific mechanical energy requirement. Product temperature according to [5] is a suitable parameter for a system analysis of extrusion cooking.

Effect of extrusion variables on product temperature

The machine was operated at the constant speed of 225 rpm at varying die diameters and moisture content, different results were observed. Figure 1 is for 4 mm die diameter, extrusion began at about 10 minutes for 20 and 30 % moisture content and at about 15 minutes for 40 % moisture content. There was no significant difference in the plotted curves for the product temperature for 20 and 30 % moisture content while the curve from the product temperatures from material with 40 % MC was below that of 20 and 30 % MC.

Figure 2 is for 6 mm diameter, extrusion begins at about the same time with when the machine was operated at 225 rpm and 4 mm die diameter. The temperature observed was slightly higher for 30 % MC compared to that of 20 % MC as the period of extrusion tend toward 1 hr:

30 m. The temperature curve for 40 % MC was slightly below the other two.

Figure 3 is for 8 mm die diameter, extrusion began at about 15 minutes for all the moisture contents. The temperature for 20% MC was higher than others between 20 to 35 minutes of extrusion before it was overtaken by the temperature of 30 % MC at about 50 minutes. The temperature for 30 % MC increases with increase in extrusion duration between 15 to 50 minutes beyond which, the temperature remained almost constant. Figure 1 to 3 shows the variations.

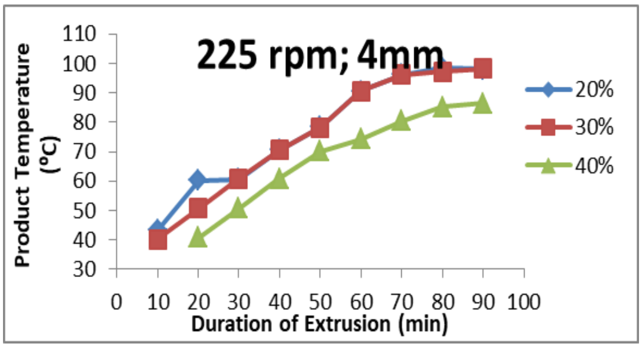

Figure 1. Variations in products temperature with extrusion time at a constant machine speed of 225 rpm and varying die diameters and varying moisture contents

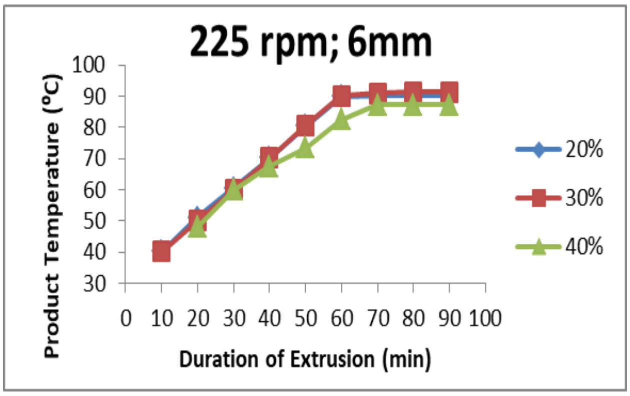

Figure 2. Variations in products temperature with extrusion time at a constant machine speed of 225 rpm and varying die diameters and varying moisture contents

The highest temperature of 98.25ºC was observed when the extruder was operated at the speed of 225 rpm with 4 mm die diameter and fed material moisture content was 30 %. 45ºC temperature which was the lowest was recorded when the extruder was operated at the speed of 334 rpm, 8 mm die diameter and the moisture content of the fed materials was 40%.

The obtained results showed that feed product temperature increases with increase in the duration of extrusion. The increase in die diameters led to decrease in product temperature which could have been from the reduction in the pressure built-up as a result of the increased discharge outlet from the larger die diameter. This conformed to [9]. It was also observed that with increase in moisture content the product temperature decreases which was also supported by [9].

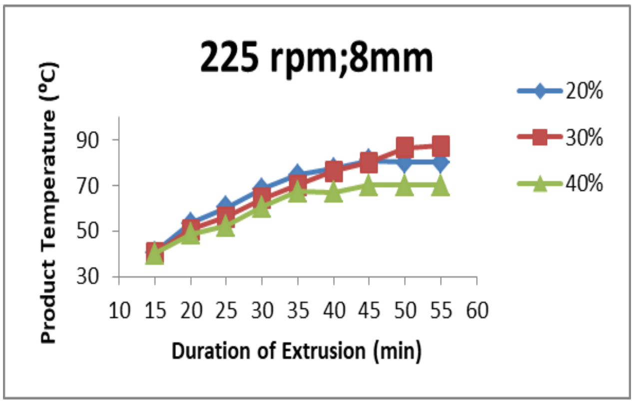

Figure 3. Variations in products temperature with extrusion time at a constant machine speed of 225 rpm and varying die diameters and varying moisture contents

Effect of Extrusion Variables on System Mechanical Energy

The System Mechanical Energy is a common measure of the extrusion energy consumption which indicates the relative ease with which a material can be extruded. The increase in the machine speed from 158.5 rpm to 245 rpm when the die diameter and the material moisture content were kept constant, it was observed from figure 4 that the specific mechanical energy decreases. (28.40 to 26.60 kJ/kg for 4 mm die diameter; 20 % moisture content, 24.70 to 23.80 kJ/kg for 6 mm die diameter; 30 % moisture content to mention a few).

Figure 5 shows further increment in the machine speed from 245 rpm to 334 rpm when other variables were kept constant, a decrease in system mechanical energy were observed except for when the machine was operated with 3 mm die diameter and 20 % moisture content which acted otherwise. Also figure 6 shows the decrease in System Mechanical Energy which was observed when the machine was increased from 245 rpm to 334 rpm at 245 rpm with 4 mm die diameter and 20 % moisture content which was in contrast with the response for others could have been from the machine trying to extrude more materials through a small orifice. It was also observed that increase in die diameter when other variables were kept constant led to decrease in the System Mechanical Energy of the machine as supported by [14].

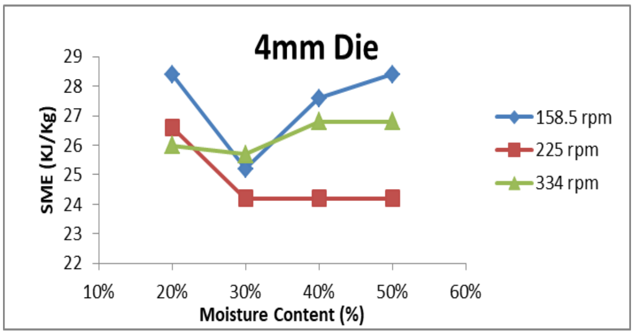

Figure 4. Graphs for system mechanical energy versus duration of extrusion of varying die diameters for the various moisture contents

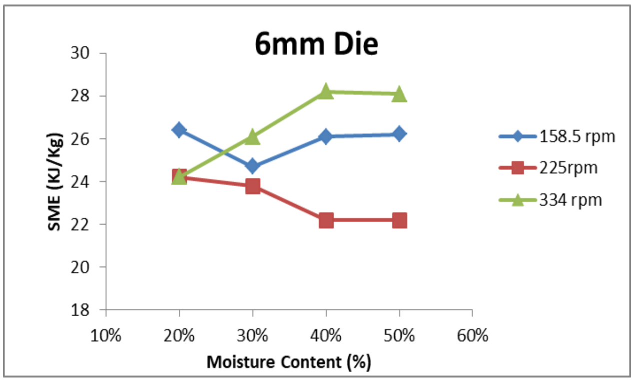

Figure 5. Graphs for system mechanical energy versus duration of extrusion of varying die diameters for the various moisture contents

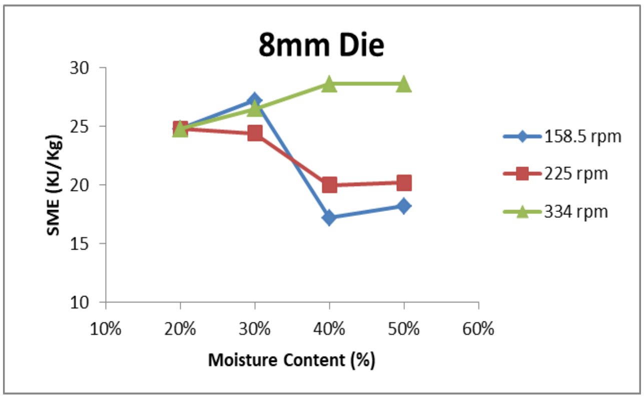

Figure 6. Graphs for system mechanical energy versus duration of extrusion of varying die diameters for the various moisture contents

Extruder Efficiency

Figure 7 shows when the machine was operated at 4 mm die diameter, the machine efficiency for the various speed increases as moisture content of the materials were increased from 20 to 30 %. While there were decreases in the efficiency on further increase in the moisture content from 30 to 40 %. It was also observed that the increase in machine speed from 158.5 rpm to 225 led to an increase in extrusion efficiencies except when the machine was operated with 6 mm die diameter from 75.50 to 72.00 %. It was observed in figure 8 that further increase in the machine speed from 225 to 334 rpm led to a decrease in extrusion efficiencies as reported by [14] except when the machine was operated with 8 mm die diameter and there was an increase in the efficiency from 66.40 to 75.30 %. It was also observed that the efficiencies at 20 % moisture content were higher than the efficiencies at 40 % moisture content. The highest extrusion efficiency of 80.00 % was recorded when the machine was operated at 225 rpm machine speed, 6 mm die diameter at 30 % moisture content while the lowest machine efficiency of 64.00 % was recorded when the machine was operated at 158.5 rpm machine speed, 4 mm die diameter at 20 % moisture content.

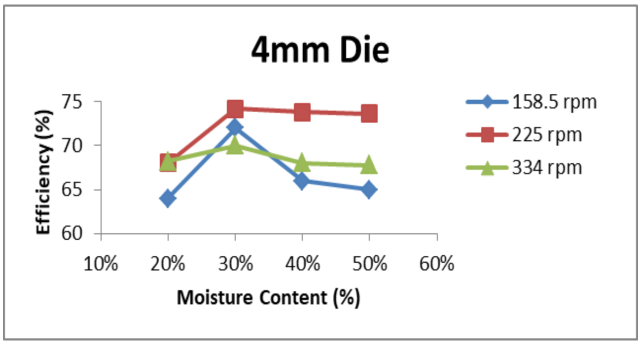

Figure 7. Graphs for extrusion efficiencies of the developed machine against varying moisture content, varying machine speed and die diameters

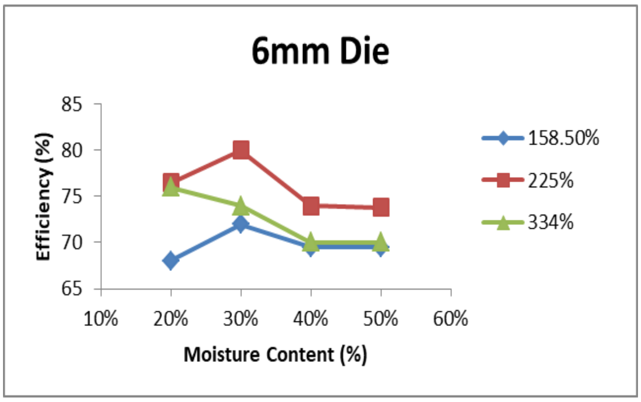

Figure 8. Graphs for extrusion efficiencies of the developed machine against varying moisture content, varying machine speed and die diameters

Product Quality Attribute

The product quality attributes studied include the product moisture content and the expansion ratio.

Effect of extrusion variables on product moisture content

The relationship between product moisture content and initial moisture content variables is a direct proportionality, as one increases, the other also increases. It was observed in figure 9 that the product moisture content decreases from 158.5 to 225 rpm but it increases from 225 to 334 rpm in figure 10, this must have been as a result of the less time spent by the materials in the extruder when the machine was been operated at 334 rpm thus not giving enough room for the extruder temperature to act proper on the materials. The product moisture was directly proportional to the die diameter. The increase in the die diameter encourages increase in the product temperature. The highest product moisture content of 40 % was observed in figure 11 when the extruder was operating at the speed of 334 rpm; die diameter of 8 mm and the initial moisture content of the materials fed 50%

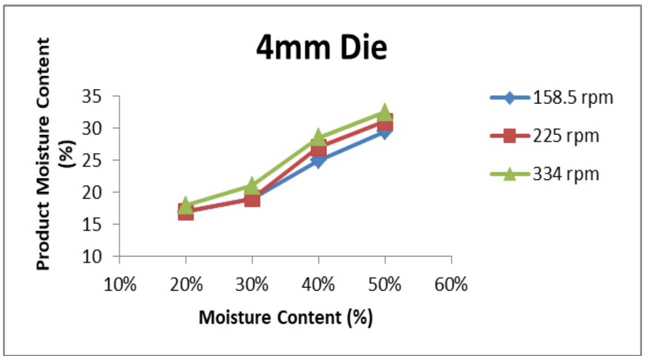

Figure 9. Relationships between product moisture content and initial moisture content for various die diameters and machine speeds

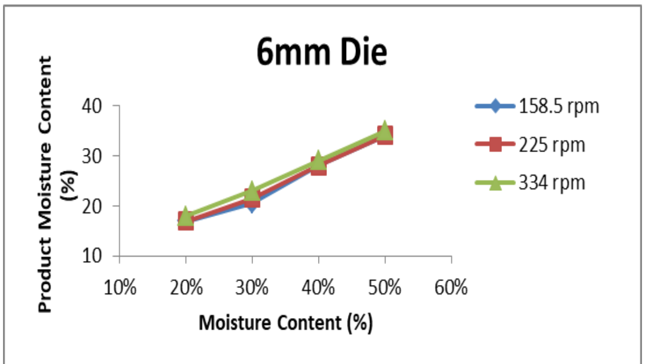

Figure 10. Relationships between product moisture content and initial moisture content for various die diameters and machine speeds

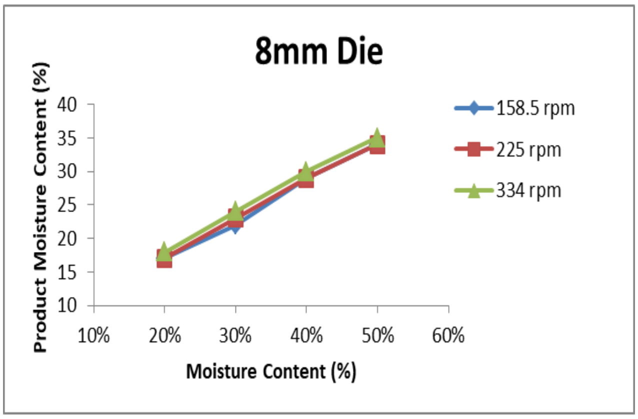

Figure 11. Relationships between product moisture content and initial moisture content for various die diameters and machine speeds

Effect of extrusion variables on expansion ratio

When the machine was operated at the constant speed of 225 rpm at varying die diameters and moisture content, different results were observed. The expansion ratios were high when the machine was operated with 4 mm and 6 mm die diameters. Figure 12; For 30 % moisture content with 4 mm die diameter at 225 rpm speed, extrusion began at about 10 minutes but expansion became noticeable at about 15 minutes of extrusion and above. While for 20 % and 40 % moisture content, extrusion began at about 15 minutes while expansion became notice able from 18 minutes and above. It was observed that the expansion ratio was relatively low for 8 mm die diameter. The relationships between expansion ratio against duration of extrusion for 225 rpm speed at varying die diameters and moisture contents is shown in the Figure 13 and 14.

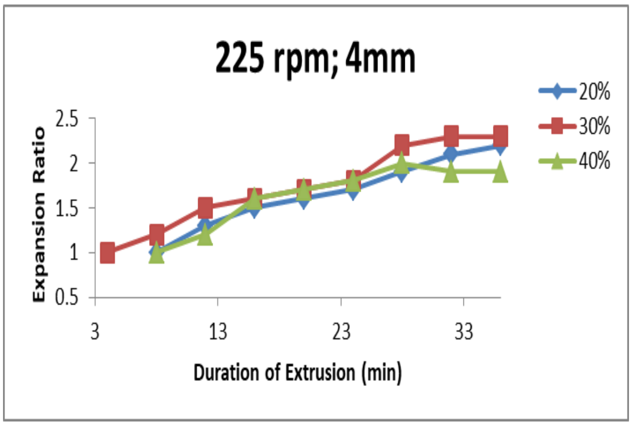

Figure 12. Relationships between expansion ratio against duration of extrusion for 225 rpm speed at varying die diameters and moisture contents

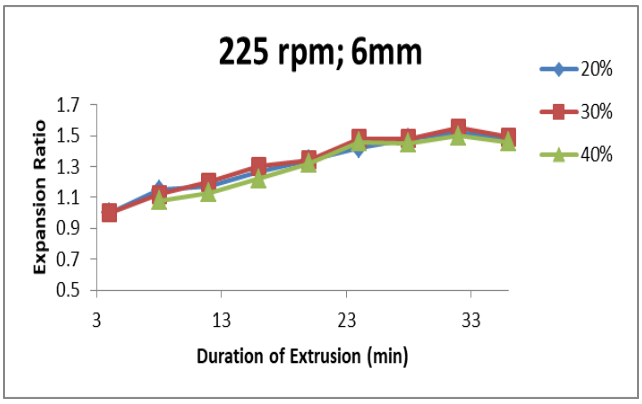

Figure 13. Relationships between expansion ratio against duration of extrusion for 225 rpm speed at varying die diameters and moisture contents

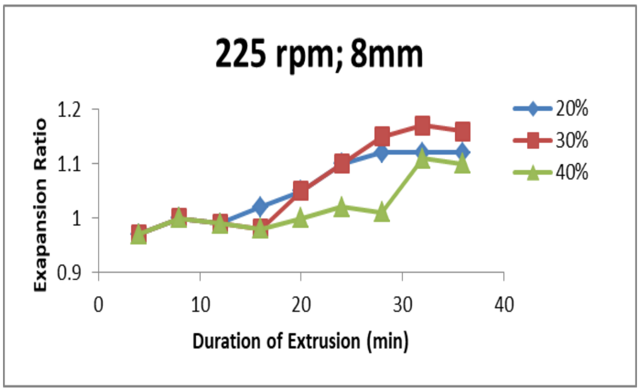

Figure 14. Relationships between expansion ratio against duration of extrusion for 225 rpm speed at varying die diameters and moisture contents

Bulk Density

Figure 15 below show the relationship between the bulk density and moisture content for varying speed and die diameters. When the machine was operated with 4 mm die diameter in figure 15; highest bulk density range were gotten for 158.5 rpm speed compared to when the speeds were 225 rpm. There was a distinct difference in the bulk densities recorded for the varying speed. For 6 mm and 8 mm die diameter in figure 16 and 17, when the machine was operated at 225 and 334 rpm, close bulk density range was recorded.

It was observed generally that as the speed increases, the bulk density reduces. This decrease in the bulk density could be as a result of the decrease in the time spent by the material within the extruder chamber due to the speed. It was also observed that as the moisture content increases, the bulk density decreases which conform to [8]. The increase in die diameter also reduces the bulk density. This reduction in bulk density could be as a result of the decrease in the pressure inside the extruding unit as a result of the larger orifice from the increased die diameter.

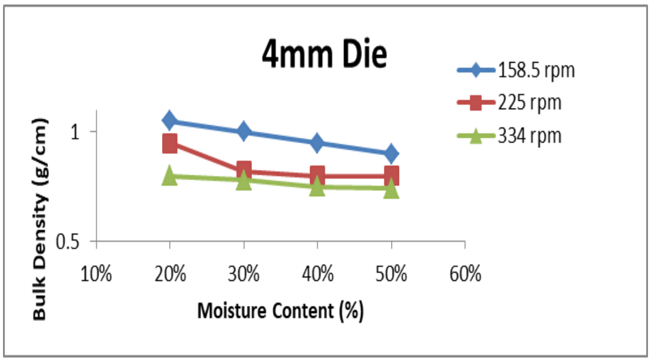

Figure 15. Relationships between bulk density and moisture content at varying speed and die diameters

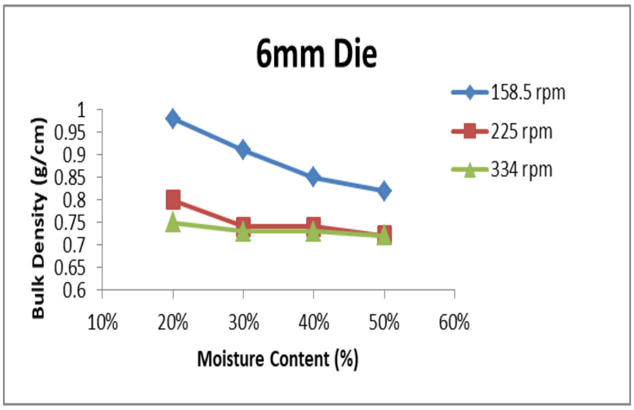

Figure 16. Relationships between bulk density and moisture content at varying speed and die diameters

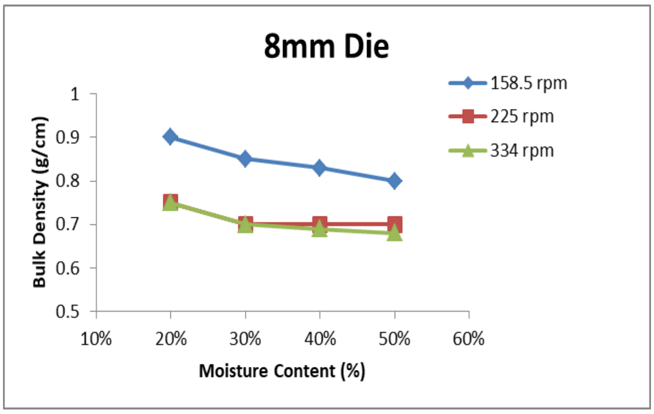

Figure 17. Relationships between bulk density and moisture content at varying speed and die diameters

Conclusions

The performance in terms of the system and product parameters of a locally developed floating fish feed extruder was evaluated on three factors namely: screw speed, moisture content and die size. The experimental results showed that increment of speed from 158.5 rpm to 225 rpm tend to increase in extrusion efficiency from 64.00 % to 68.00 %. And decrease in bulk density from 1.05 to 0.95 g/cm^3; reduction in specific mechanical energy from 28.40 to 26.60 kJ/kg, when screw speed is further increase from 225 to 334 rpm extrusion efficiency reduced from 74.20 to 69.00 %, and bulk density from 0.82 to 0.78 g/cm^3 and increase in specific mechanical energy from 24.20 to 25.70 kJ/kg. It was observed that increase in moisture content from 20 % to 30 % tend to decrease the specific mechanical energy from 28.40 to 25.20 kJ/kg, bulk density from 1.05 to 1.00 g/cm^3 and increase the extrusion efficiency from 64.00 to 72.00 %. When moisture content increase from 30 % to 40 %, there is increase in specific mechanical energy from 25.20 to 27.60 kJ/kg, and decrease in extrusion efficiency from 72.00 to 66.00 %, reduce bulk density from 1.00 to 0.95 g/cm^3. Different parameters involved in the extrusion process (machine speed, moisture content of the fed materials and the die diameters) are important and interrelated. The study revealed that it is better to fix the extrusion variable at the moderate values to enhance the extrusion performance.

Conflict of interest

Authors declared no conflict of interests.

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