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ABSTRACT

Abstract Development of fish feed technology in aquaculture sector is very low in Nigeria due to poor techniques involved in formulation and processing. This study examined the influence of machine and process parameters on the performance of a floating fish feed single screw extruder and a blend of feed mixture was used for the experiment. The influence of the experiment on the extrudate responses were studied using response surface methodology. Moisture contents wet basis of (20 %, 30 % and 40 %) and screw speed of (158.5 rpm, 245 rpm and 334 rpm) were used. Analysis of variance showed the effect of screw speed on expansion ratio, specific mechanical energy and machine efficiency to be significant and effect of moisture content on floatability, sinking velocity and expansion ratio to be significant. While floatability increased with increased screw speed and increased moisture content and sinking velocity decreased with increased screw speed and increased with increased moisture content. Expansion ratio increased with increased screw speed and moisture content. Specific mechanical energy increased with increased screw speed and decreased with increased moisture content. The extruder efficiency decreased with increased speed and moisture content.

Keyword: extruder, extrudate; floatability; surface response methodology; efficiency.

1. INTRODUCTION

Fish feed technology is one of the least developed sectors of aquaculture particularly in Africa and other developing countries of the world (FAO, 2003). Feed has been one of the major inputs in aquaculture production. It is one of the fundamental challenges facing the development and growth of aquaculture in the African continent. Fish requires high quality nutritionally balanced diet for growth and attainment of market size within the shortest possible time. Feed supply has been the major source of the fall in the fish production activities. Farmers use cheap and locally sourced raw ingredients to produce feeds that are badly formulated, poorly made and misguidedly used due to a lack of technical expertise and inadequate manufacturing equipment in their on-farm feed manufacture despite the availability of the feed ingredients (Gabriel *et al.*, 2007).

Regular and adequate supply of balanced artificial diets for the cultured fishes is crucial for any aquaculture venture to be viable and profitable (Ugwumba and Ugwumba, 2003). Therefore local production of fish feed is very important to the development and sustainability of aquaculture in Africa especially, in the rural areas and also for aquaculture to thrive and bridge the already existing wide gap between fish demand and supply especially in Africa.

Extrusion is one of the most commonly applied food processing technique in food industry. It is now a very popular processing technique used in the feed, cereal, and snack food industries (Delgado-Nieblas *et al.*, 2012) and also one of the most versatile unit operations (Forsido *et al.*, 2011). Extrusion cooking is a versatile, low-cost and efficient food processing technique which cooks more rapidly than other techniques because it combines moisture, pressure, temperature and mechanical shear. It induces numerous chemical and structural



transformations such as starch gelatinisation, protein denaturation, complex formation between amylase and lipids, and degradation of vitamins or pigments in starchy and proteinous food materials (Ding *et al.*, 2005).

The goals of the extrusion process include cooking, sterilization, expansion, texturization, and product shaping (Liu and Rosentrater, 2011). It is also a thermo-mechanical treatment in which moistened, expansible, starch and proteinous materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear and pass through the die opening with a pre-define shaped at extruder outlet (Smith, 1976). Extrusion is one of the bulk deformation processes used in manufacturing of various products. It enables mass production of food through continuous, efficient system that ensures uniformity of the final product which is achieved by controlling various aspects of the process. It is also used for the production of new processed food products and "revolutionized many conventional snack manufacturing processes (Riaz, 2000). Extrusion cooking of aquaculture feeds involves reduction of ingredients into uniform particles size to produce flours giving increased surface area of all ingredients for better mixing and uniform moisture uptake. Hammer mills are mostly used grinders for Aqua feeds production. Mixing of ingredients in a desired proportions by mixing dry flours first followed by other ingredients such as Vitamin 'premixes', binding agents and other additives. (Jovanovic *et al.*, 2009; Malik, 2011).

There are several types of extruders which are used for processing food and feed products. They are single screw, twin screw, some have internal steam locks, some have grooved barrels, some have continuous flights, and others have interrupted flights. Some extruders generate their own heat by friction for cooking and other use additional heat sources like steam for cooking purposes (Riaz, 2007). Extruders can also be classified according to the method of operation such as cold extruders or worm extruder cookers and the method of construction single or twin-screw extruders (Vijayagopal, 2004). Extrusion with steam preconditioning is known as wet extrusion and extrusion without steam preconditioning is called dry extrusion (Vijayagopal, 2004).

There are two important factors that affect the efficiency of an extruder and the quality of the extrudates. They are the process parameters and the machine parameters. The quality of the extrusion product depends greatly on process parameters which are the extruder type, screw speed and configuration, the temperature profile in the barrel sections of the extruder and the moisture content of the raw material (Zhuang *et al.*, 2010). Although several research experiments have been carried out on food and feed extrusion as well as extrusion technology as a whole but much has not been done on the locally fabricated single screw extruder. However this research work was carried out to evaluate the effect of machine and process parameters on the efficiency of the single screw extruder and optimize the relationship between the parameters involved as it affects the efficiency of the extruder machine.

2. Materials and Methods

2.1 Experimental material

The experiments carried out in this work made use of a single screw Extruder that was fabricated at the department of Agricultural and Environmental Engineering workshop of the Federal University of Technology, Akure, Nigeria. The extruder consists of a steel barrel which houses the extrusion worm equipped with a hopper which is the feeding unit at one end and a die plate where the extrusion takes place at the other end of the barrel. The machine was powered by a 25hp 3-phase electric motor while the power transmission is accomplished through chains and sprockets. Two vents are located at the compression and the discharge zones of the extrusion barrel through which extrusion temperature was monitored during the experiment.

The materials for the feed blend used for the experiment was procured from a metropolitan market in Akure, Nigeria.

2.2 Experimental Design and Analysis

Already mixed raw material were fed into the extruder using a bowl, the operation conditions (machine speed and moisture content) were continuously monitored and feed rate and particle size were kept constant during a time corresponding to three times. The transformation of a soft, often dusty feed into a hard pellet was accomplished by compression, extrusion and adhesion. Moisture provided lubrication for compression and extrusion in the presence of heat caused some gelatinization of raw starch present on the surface of vegetative ingredients which resulted in adhesion. Machine speed of 158.5 rpm, 245 rpm and 334 rpm were used alongside the three die sizes



of 4 mm, 6 mm and 8 mm. Within 15min of entering the extruder, feed goes out from the die opening and cut into sizes by the cutter that is attached to the end of the machine, pellets were discharged onto a bowl.

Sample of the feed weighing 3 kg was prepared at moisture content of 20% and was tested at three machine speeds of 158.5 rpm, 245 rpm and 334 rpm respectively. The speed of the machine was varied by changing the chain and the sprocket of the machine to give three different speed values for each replicate. These processes were repeated for additional two moisture contents of 30 %, and 40 % respectively, thereby making the samples tested to be 27. The extruded products at different levels of variable combination were dried manually by spreading inside a direct sunshine. Some samples of the product to be used for chemical test was taken immediately after the experiment and tied inside a water proof material. Box-Behnken design (BBD), a tool in Design- Expert was used in the optimization of process variables with five factors at three levels with 24 runs, including 5 central points. The response function was partitioned into linear, quadratic, and interactive components. Analysis of variance (ANOVA) was applied to study the influence of process parameters (screw speed and moisture content) and their interactions on the extrudates responses (floatability, sinking velocity, expansion ratio, specific mechanical energy and efficiency of the machine) while p value of 0.05 was used as the significant value

3. RESULTS AND DISCUSSION

The result of the experiment showed the effects of machine parameters on the extrudates response

3.1 Effect of screw speed on machine and extrudate responses

Figure 1 showed that there was relative increase in efficiency of the machine as the screw speed increased but the efficiency decreased with high screw speed which showed that a very high screw speed did not show the effectiveness of the machine while figure 2 showed that extrudates ability to float is a function of how well cooked the extrudates was, which explained that increased in screw speed produce more heat needed for the extrudates to cook and become lighter to be able to float. Figure 3 shows that changes in screw speed did not affect the sinking velocity i.e that extrudate maintains its ability to sink in water regardless of the screw speed with which it was processed. However, figure 4 showed greater expansion with increased speed and figure 5 showed that the speed of the machine has a direct effect on the specific mechanical energy of the machine which means that the extruder machine was at its best at the lowest speed.

3.1.1 The specific mechanical energy

$$E_m = \frac{S_w}{S_r} \times \frac{T_m}{100} \times \frac{P_m}{F_r} = \quad (1.1)$$

Where

E_m = specific mechanical energy (%)

S_w = actual screw speed (rpm)

S_r = rated screw speed (rpm)

T_m = % motor torque (N/m)

P_m = motor power (kj/h) and

F_r = mass flow rate (kg/h)

3.1.2 Extruder efficiency (η_p)

Extruder efficiency was determined using the following formulae

$$(\eta_p) = \frac{W_A}{T_F} \quad (1.2)$$

Where

W_A is the quantity of actual feed pelleted obtained at the main die orifice

T_F is the total feed input (kg)

Where

$$T_F = Q \times k \quad (1.3)$$

And

T_F is the total feed input (kg)

Q is the feed rate (kg/h)

K is co-efficient of friction between barrel wall and feed material

3.2 Effect of moisture content on machine and extrudate responses

Moisture content is a determining factor for cohesiveness while water activity values indicate shelf life. Moisture content is an important factor for consideration because it determines the freshness of the pellets and also impacts the rate of spoilage of extrudates. Figure 6 showed that efficiency increased with increase moisture content, Figure 7 showed that floatability increases with increase in moisture content and figure 8 showed that expansion ratio increased with increased moisture content while figure 9 showed that sinking velocity was recorded with the highest moisture content while explained that the material expansion ratio decreased as the moisture content increased, however figure 10 showed that the specific mechanical energy required of the machine decreased with increased in moisture.

3.3 Desirability of the analysis

The desirability of the analysis showed the final result from the optimization carried out. It showed that the desired screw speed for the machine was 251.015rpm at moisture content 40% for floatability 37, sinking velocity, expansion ratio 1.057 and specific mechanical energy of 30.4.

4. CONCLUSION

Extrusion of floating fish feed was carried out using a single screw extruder. Three levels of the dependent variables screw speed of 158.5 rpm, 245 rpm and 334 rpm and moisture content of 20 %, 30 % and 40 % were used and five output parameters such as expansion ratio, floatability, specific mechanical energy, sinking velocity and machine efficiency were obtained. The three levels of dependent variables were statistically analyzed against the output parameters. Based on this study, the extruder machine screw speed has a significant effect on the machine efficiency while the material moisture content used in the study did not affect the machine efficiency. However the machine best efficiency by optimization result was 78.95% at moisture content 40%, screw speed 261.015 rpm which produced 37.26% floatability, 19.63 sinking velocity with 1.067 expansion ratio and 28.19 specific mechanical energy. The desirability of the experiment is 0.706. In conclusion it showed that the machine parameters has significant effect on the efficient performance of the extruder.

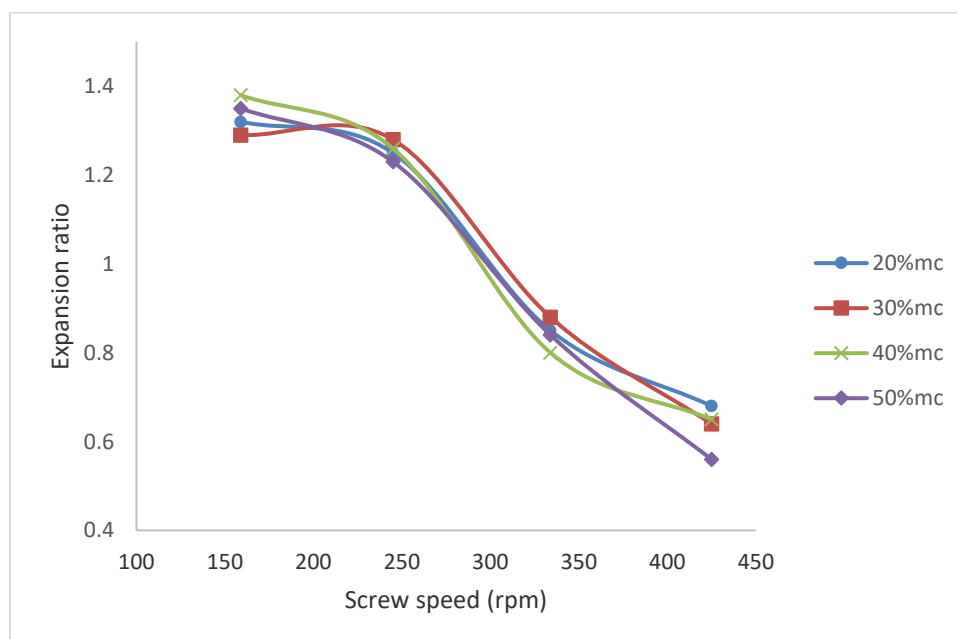


Figure1: Effect of screw speed on the Expansion ratio at different moisture content

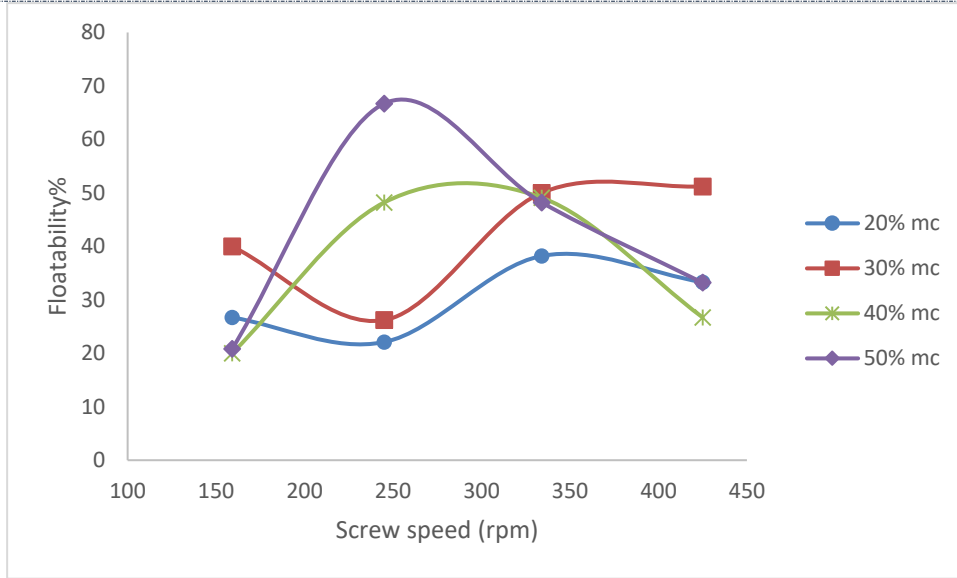


Figure2: Effect of screw speed on the Floatability of Extrudate at different moisture content

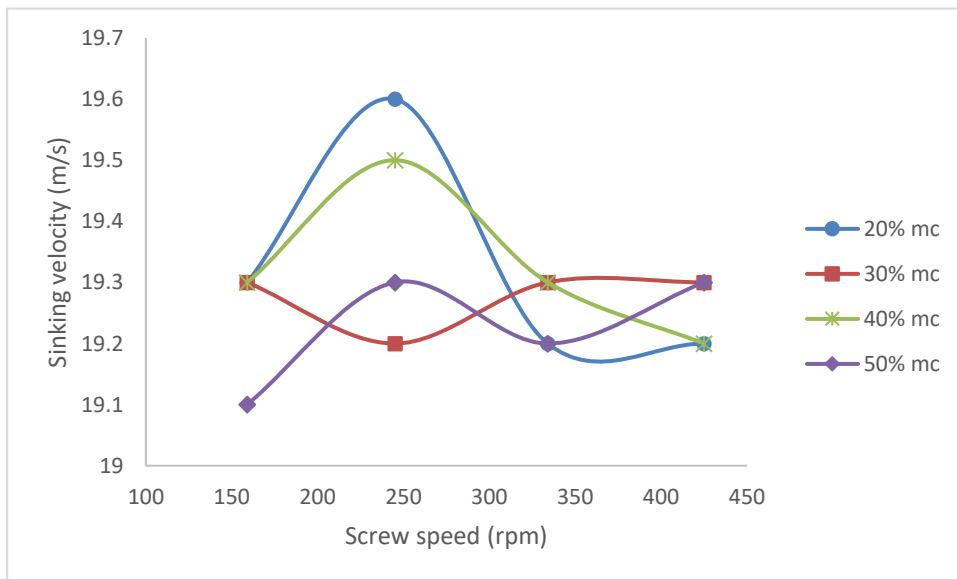


Figure3: Effect of screw speed on the Sinking velocity at different moisture content

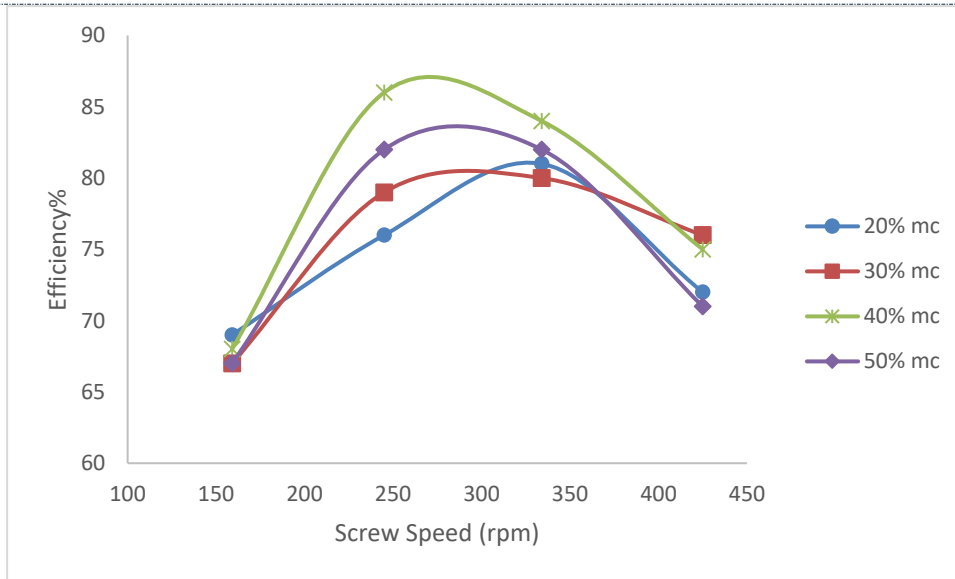


Figure4: Effect of screw speed on the Efficiency of Extruder at different moisture content

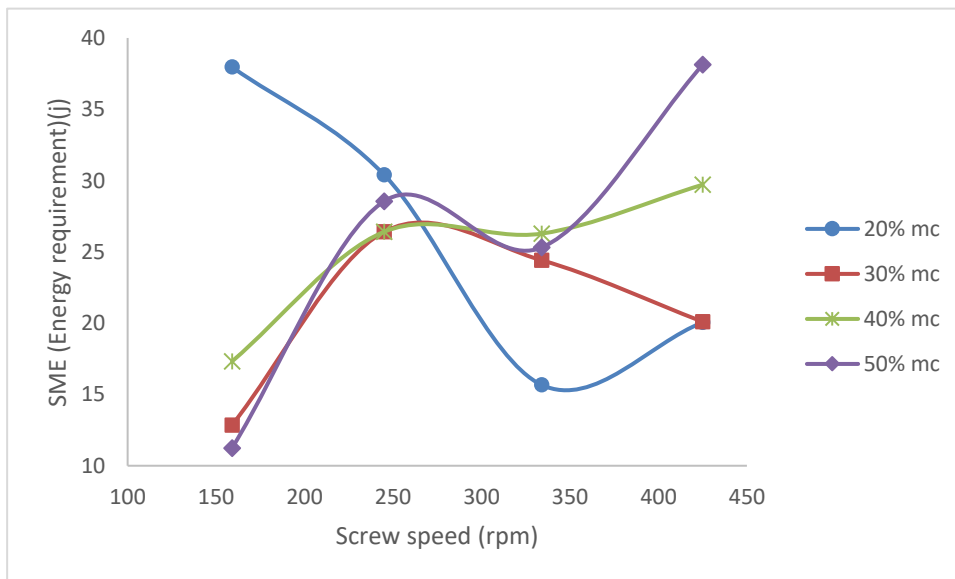


Figure5: Effect of screw speed on the Energy requirement of the Extruder at different moisture content

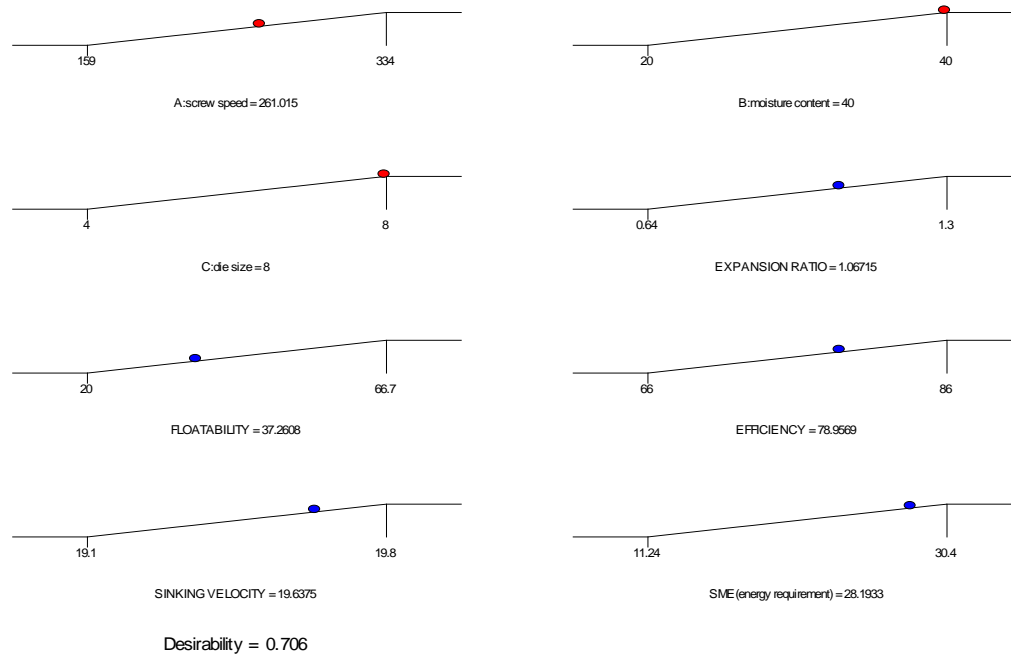


Figure6: Desirability curve of the analysis

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Conflict of interest

The authors declare that there is no conflict of interest.

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