International Journal of Modern Science and Technology, 2020;5(11):266-273.
ISSN: 2456-0235.
www.ijmst.co

Research Article

The effect of extrusion variables of a locally developed single screw floating fish feed extruder

O. S. Ogundana*[1], A. P. Olalusi[2], J. Isah[2]

[1]*Department of Agricultural Technology, Federal College of Freshwater Fisheries Technology New Bussa, Niger State. Nigeria.*

[2]*Department of Agricultural and Environmental Engineering, Federal University of Technology Akure, Ondo State. Nigeria.*

*Corresponding author's e-mail: odunmamsam@gmail.com

Abstract

The present study examined the influence of product and process parameters on the performance of a locally developed single screw floating fish feed extruder. The influence of the experiment on the extrudates responses were studied using response surface methodology. Moisture contents wet basis of (20, 30 and 40 %), die size of (4, 6 and 8 mm), and screw speed of (158.5, 245 and 334 rpm) were used. Analysis of variance showed the effect of screw speed on floatability, it increase with increase in screw speed, having a greater expansion ratio with increase speed, speed as direct effect on specific mechanical energy and extruder efficiency. Effect of die size, increase in floatability, specific mechanical energy, with a relative increase in die size. Sinking velocity is not affected by the die size while die size have great effect on expansion ratio 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.

Keywords: Extrudates; Extruder; Evaluation; Fish feed; Floating; Speed.

Introduction

Aquaculture is one of the fastest growing food production activities in the world. It plays a significant role in many countries by providing a higher income, better nutrition, and better employment opportunities [9]. Modern nutrient-dense diets for most fin-fish species tend to be manufactured using a technique referred to as extrusion processing. In this process a mixture of raw materials is compressed through barrel by a screw while heat and steam are applied to the raw materials as they pass along the length of the barrel. At the end of the barrel the mixture, referred to as the mash, is extruded through a small aperture known as the die. In most extrusion techniques used in fish feed production a certain amount of starch is added to the mixture. The effect is that when the mash is extruded through the die, the release of pressure and heat causes the starch to expand and gelatinise [10]. This starch expansion along with some interactions among the proteins in the mash is what gives the product its principle binding strength.

Extruders have several types, which are used for food and feed processing. They are single screw, twin screw, some have internal steam locks, some have grooved barrels, some have continuous flights, and others have interrupted flights [11]. Some extruders generate their own heat by friction for cooking and other use additional heat sources like steam for cooking purposes [13]. 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 [16].

Received: 28.10.2020; Received after Revision: 19.11.2020; Accepted: 20.11.2020; Published: 04.12.2020.

Depletion of wild fisheries, combined with rising demands for seafood products for human foods, has led to increased aquaculture production during the last several decades. Depending upon the species and maturity, fish have high dietary protein demands of up to 55% [6]. Development of fish feed technology in aquaculture sector is very low particularly in Africa and other developing countries of the world [6]. Feed as one of the major inputs in aquaculture production is facing fundamental challenges of development leading to poor growth of aquaculture in the African continent. Fish feed development in Sub-Saharan Africa has not made a significant progress in aquaculture as expected. Development and management of fish feed, play a very vital role in aquaculture growth and expansion and also it is a major factor that determines the profitability of aquaculture venture [7].

Feed accounts for at least 60% of the total cost of fish production in Africa, which to a large extent determines the viability and profitability of fish farming enterprise [8]. Fish feed constitutes between 50% and 70% of a commercial farmer's cost of production [11]. As aquaculture becomes intensive, most farmers in Africa depend largely on imported feed because locally produced high-quality fish feed is not available in circulation. Lack of affordable, quality manufactured feeds has been one of the major factors that have impeded the development of the aquaculture sector across Africa resulting in inconsistent supplies [7]. Challenges in making feeds in Nigeria are not in sourcing the ingredient but on the techniques involved in formulation and processing. However this research work was carried out to evaluate the effect of extrusion processing condition of a locally developed single screw floating fish feed extruder.

Materials and methods

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 25 hp 3-phase electric motor while the power transmission is accomplished through chains and sprockets (Fig. 1). Two vents are located at the compression and the discharge zones of the extrusion barrel through which extrusion temperature was monitored during the experiment. Cassava tubers (Manihot esculenta Crantz) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour. The materials were passed through a 300 µm sieve and moisture contents of sample were determined as described by [3] approved method. The feed materials used for the experiment were procured at various mills in Akure, Ondo state and Cossy fish integrated in Kainji, Niger state. The materials were prepared and processed by the standard recommended by Nigerian Institute for Oceanography and Marine Research (NIOMR) approved method. The percentage of samples recipes for the experiment is as follows: Cassava 39 %, Soy meal 20 %, Groundnut 20 %, Fish meal 20 %, Fish premix 0.5 %, Nitox antimould 0.5 %.

Experimental design and analysis

Sample of the feed weighing 3 kg was prepared at moisture content of 20% and was tested at three machine speeds of 158.5, 245 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, and die size of 4, 6, and 8 mm respectively. The extrudates discharged were cut automatically with cutting blade to lengths proportional to the expanded die diameter. The extruded products at different levels of variable combination were dried manually by spreading inside a direct sunshine. 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 responses function was partitioned into linear, quadratic, and interactive components. Analysis of variance (ANOVA) was applied to study the influence of process parameters (screw speed, die size 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 [12].

Fig. 1. Pictorial view of the extruder machine

Statistical Analysis

This experiment was conducted using a factorial design comprising of three levels of the dependent variables (screw speed, die size and moisture content) were analysed against the output parameters such as expansion ratio, floatability, specific mechanical energy and sinking velocity, expansion ratio and their result were plotted. One way ANOVA, least significant follow up tests, and step-wise multiple regression analysis were carried out using Statistical Package for Social Scientists (SPSS 13.0) software while response surface methodology was performed to examine their effect on the responses.

Extrusion variables

Die size

According to [10], it is established that temperature of an extruder barrel is proportional to its die diameter. Die nozzle diameter and length play a very important role in starch extrusion expansion [1].

Moisture content

The moisture contents of the extruded feed were determined on dry basis by an oven drying method. About 10g 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.

Screw speed

Changes in screw speed effects the extrusion parameters except for the temperature of the die [4] while increasing the screw speed resulted in a decrease in bulk density because of greater expansion [4].

Product parameter

Specific mechanical energy

The Specific Mechanical Energy (SME) was calculated from the screw speed n (rpm), motor torque T (N m), and mass flow rate MFR (g/min) by the eq. [1].

$$SME = \frac{Actual\ screwspeed\ (rpm)}{Rated\ screwspeed\ (rpm)} \times \frac{\%\ motor\ torque}{100} \times \frac{motor\ power\ (kj/h)}{mass\ flowrate\ (kj/h)} \qquad (1)$$

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 using the eq. (2).

$$EC = \frac{M_e}{T} \qquad (2)$$

Where; EC is the extrusion capacity (kg/min), Me is the mean mass of the extrudates for each treatment (Kg), T is the 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 eq. (3).

$$RE = \frac{M_e}{M_i} \qquad (3)$$

Where; RE is the extrusion efficiency (%), Me is the mean mass of extrudates (kg), Mi is the mean initial mass of ingredients (kg).

Floatation and sinking velocity test

The floatation test and sinking velocity was performed using transparent conical flask for each treatment. A specific amount of extruded feed was immersed in water and at end of every observation the number of extruded feed afloat was recorded and the times taken for the feed to sink were also recorded.

$$\% \text{ feed afloat} = \frac{\text{final number of feed afloat}}{\text{initial number of feed afloat}} \times 100 \quad (4)$$

$$\text{While sinking velocity (sv, m/s)} = \frac{h}{t} \quad (5)$$

Where h is the height of water column (m), t is the time taken by the extrudates to reach the bottom of the container (s).

Result and discussion

Effects of screw speed on the processing parameters

It was observed from fig. 2 that floatability increases with increase in screw speed. Similar finding was also reported by [14] discussed the same in feed extrusion process description that the extrudates ability to float is a function of how well cooked the extrudates is, which explains that increase in screw speed produce more heat needed for the extrudates to cook and become lighter to be able to float. The analysis of variance also shows that floatability is not significant with increase screw speed ($p>0.05$) where the F-value for floatability is 0.694. Fig. 3 shows that the sinking velocity increases with increase in screw speed.

Fig. 4 shows greater expansion ratio with increasing speed. Chevanan et al [4] reported similar result in Twin-screw extrusion processing of feed blends containing distillers dried grains with solubles (DDGS). The extrudate expansion ratio increased with increased speed because increased speed generate more heat leading to high temperature that gelatinized the extrudate thereby increasing the expansion ratio which in turn reduced rate of sinking and increased floatability however it is statistically shown that screw speed has significant effect on the expansion ratio which shows that ($p<0.05$) and the F-value for expansion ratio is 0.047.

Fig. 5 shows that the speed of the machine has a direct effect on the energy requirement of the machine. The result was in agreement with the RTD in twin-screw food extrusion, which explains that increase in machine speed increases the energy requirement while it is shown statistically that the effect of screw speed on specific mechanical energy is significant ($p<0.05$) and the F-value is 0.017. It is apparent in fig. 6 that the machine was at its best at the lowest speed. Similar result was reported by [15] in twin-screw extrusion of rice-green gram blend Extrusion and extrudates characteristics however analysis of variance shows that screw speed has a significant effect on the efficiency ($p<0.05$) and F-value is 0.022.

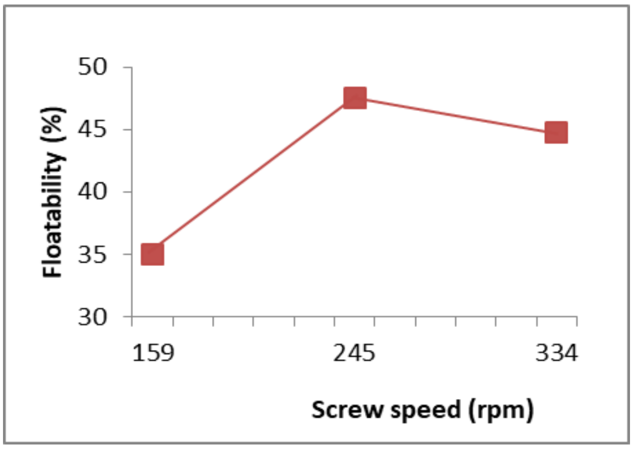

Fig. 2. Effect of screw speed on floatability

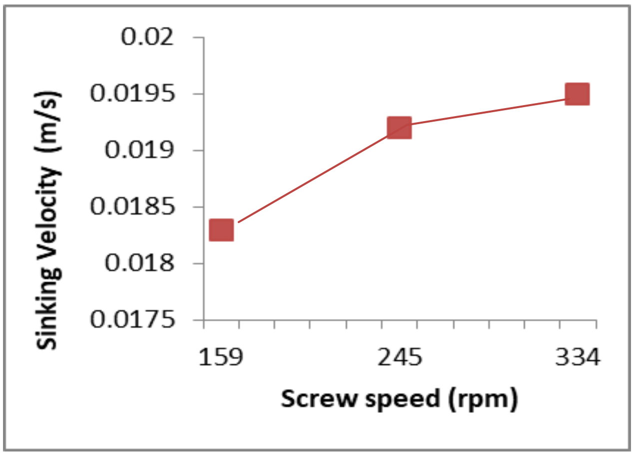

Fig. 3. Effect of screw speed on sinking velocity

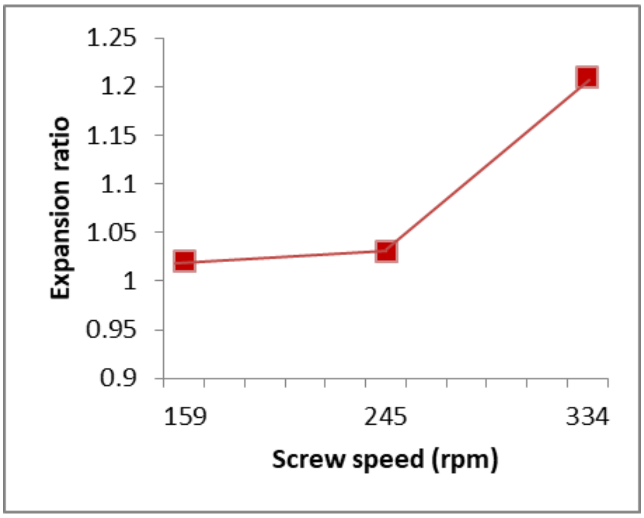

Fig. 4. Effect of screw speed on expansion ratio

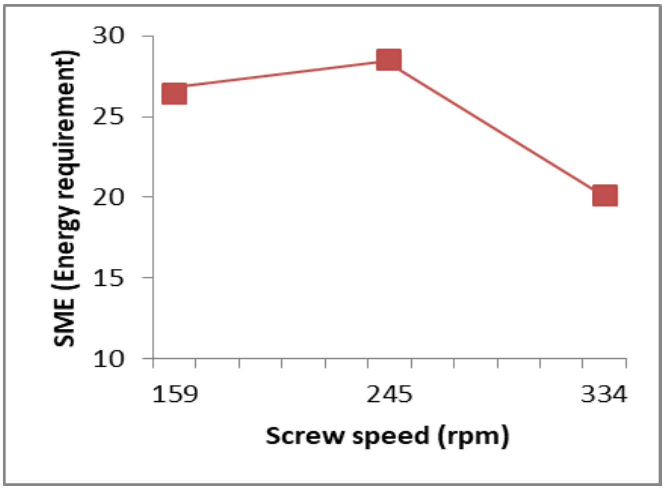

Fig. 5. Effect of screw speed on the SME

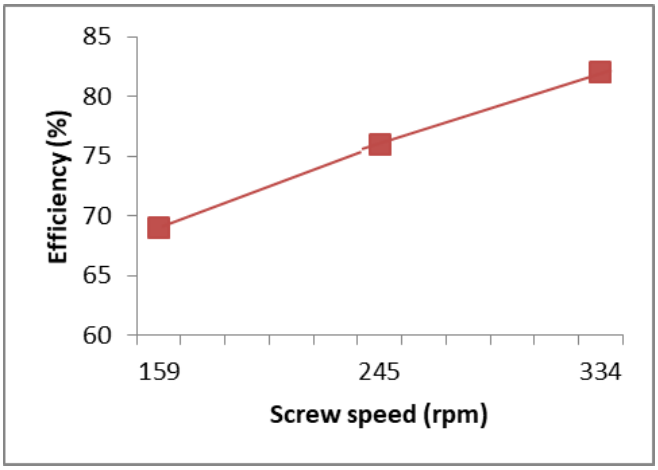

Fig. 6. Effect of screw speed on the machine efficiency

Effect of die size on the product parameters

The effects of the three die sizes on floatability of the extrudates is shown on fig, 7 which shows increase in floatability with a relative increase in die size. This was in accordance with [4] 007 in Twin-screw extrusion processing of feed blends containing distillers dried grains with soluble (DDGS) which was observed that the bigger size of the extruded feed has more ability to stay on water surface. However statistics shows that the effect of die size on floatability is significant (p =0.05) and the F-value is 0.05.

Fig. 8 shows that sinking velocity is not affected by die size. Chevanan et al [4] Reported that in Twin-screw extrusion processing of feed blends containing distillers dried grains with soluble (DDGS) explains that the diameter of the die hole does not show any effect on the ability of the extrudates floatability. Statistics shows that the effect of die size on sinking velocity is not significant (p>0.05) and the F-value is 0.144. Fig. 9 shows an increase in specific mechanical energy with increase in the die size. This was discussed by Adekola [1] in influence of food extruder die dimension on extruded product expansion.

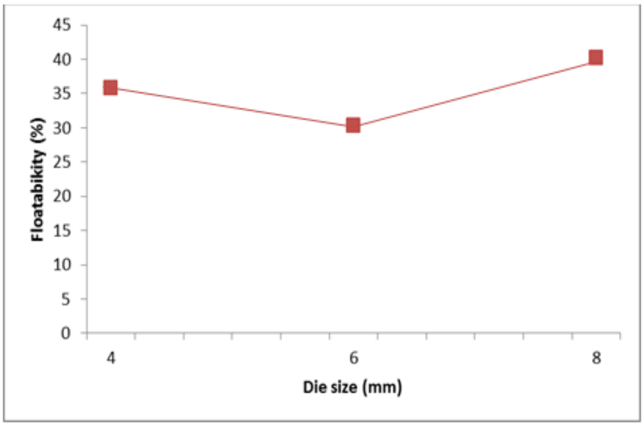

Fig. 7. Effect of die size on floatability

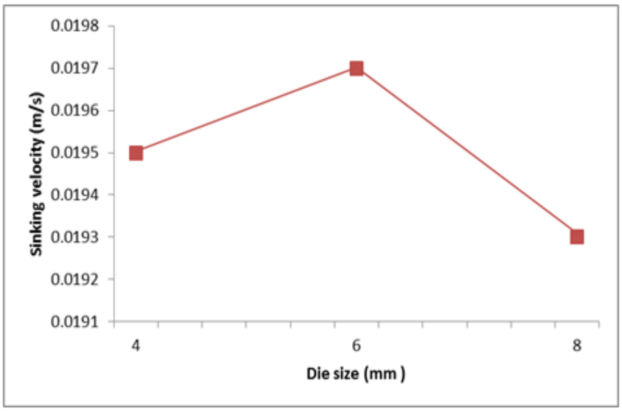

Fig. 8. Effect of die size on the sinking velocity

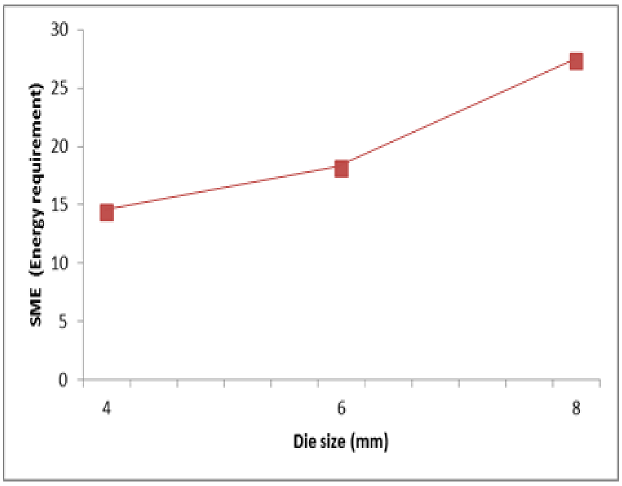

Fig. 9. Effect of die size on SME

However statistical analysis shows that increase in die size has a significant effect on the increase in specific mechanical energy (p<0.05) and the F-value is 0.074 while fig. 10 shows a significant increase in efficiency with increase in die size. This was in line with earlier researcher. It is shown statistically that increased efficiency relative to increased die size is not significant (p>0.05) F-value is 0.389. Fig. 11 shows a non-linear relationship between die size and expansion ratio thus there may be some other confounding factors that are responsible for this, however the analysis of variance shows that die size has significant effect on the expansion ratio (p<0.05) and F-value is 0.000.

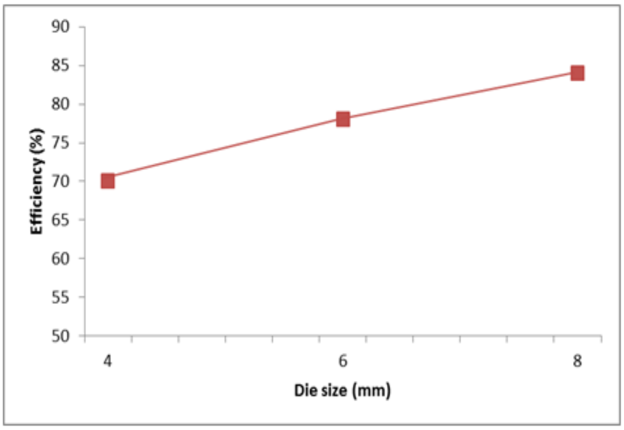

Fig. 10. Effect of die size on efficiency

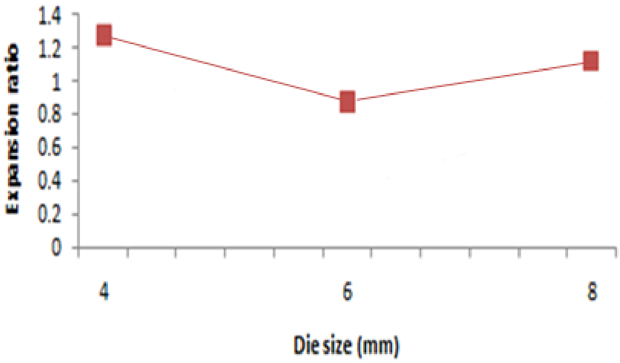

Fig. 11. Effect of die size on expansion ratio

Effect of moisture content on the product parameters

Fig. 12 shows that sinking velocity was recorded with the highest moisture content. This was discussed earlier in Optimum extrusion-cooking conditions for improving physical properties of fish-cereal based snacks by Ratankumar et al [14] which explained that changes in extrusion conditions, especially screw speed and moisture content during the extrusion process can have significant effects on the resulting physical properties and quality of the extrudates while statistical analysis confirms the effect of moisture content on sinking velocity as being significant (p<0.05) F-value is 0.033. Fig. 13 explains the effect of moisture content on the floatability which means that floatability increases with increase in moisture content as discussed by Zhuang et al [18], statistics analysis shows that the effect of moisture content on floatability is significant (p=0.05) F-value is 0.05.

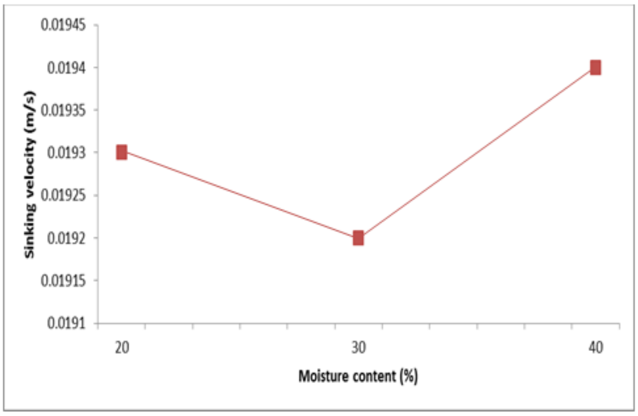

Fig. 12. Effect of moisture content on Sinking velocity

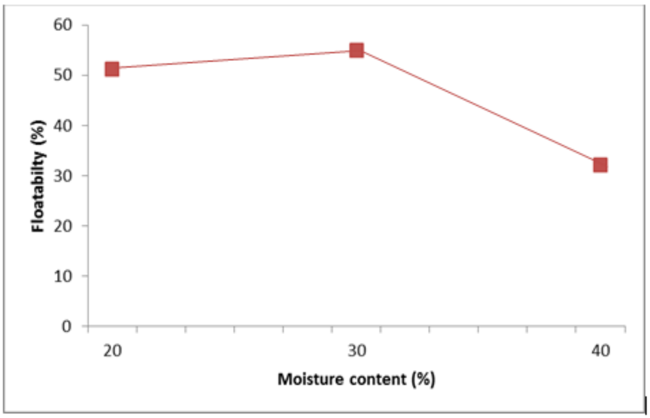

Fig. 13. Effect of moisture content on floatability

Fig. 14 explains that the material has a constant expansion ratio as the moisture content increases, but the expansion increased at the highest moisture. This effect was corroborated by Ding et al., 2005 [5] in effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks while statistical analysis shows that the effect of moisture content on expansion ratio is significant (p<0.05) F-value is 0.029. Fig. 15 shows that energy required decreased with increase in moisture. This was noted in effect of extrusion parameters on physicochemical properties of hybrid Indica rice [18]. However statistical analysis shows that effect of moisture content on energy required is not significant (p>0.05) F-value is 0.755. Fig. 16 shows the effect of moisture content on efficiency. Statistical analysis the effect of moisture content on efficiency is not significant.

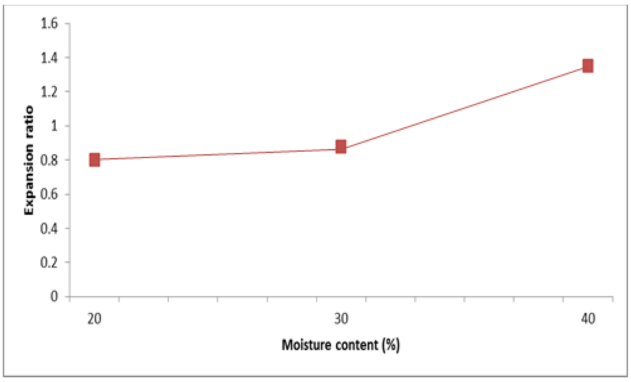

Fig. 14. Effect of moisture content on expansion ratio

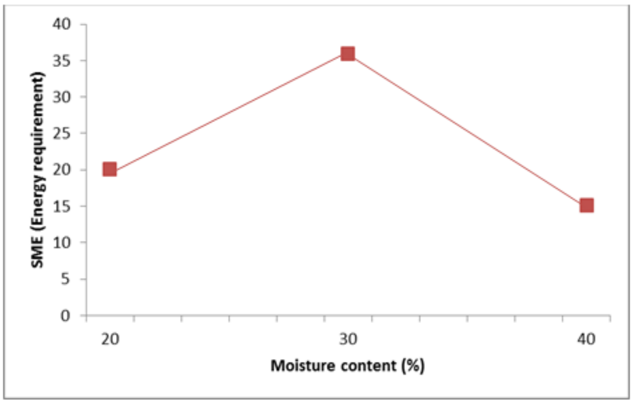

Fig. 15. Effect of moisture content on SME

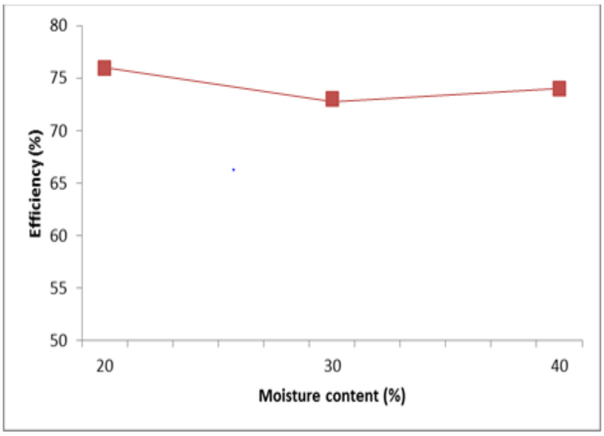

Fig. 16. Effect of moisture content on efficiency

Conclusions

Extrusion of floating fish feed was carried out using a single screw extruder. Three levels of the dependent variables screw speed of 158.5, 245 and 334 rpm, die size of 4 mm, 6 mm and 8 mm 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. The machine die size and the material moisture content used in the study do not affect the machine efficiency. However the best extrudates are obtained at the lowest screw speed of 262.015 rpm at 40 % moisture content with die size 8 mm. The extrudates has floatability ratio of 37.26 %, sinking velocity of 0.01964 m/s with expansion ratio of 1.065 and efficiency of 78.95 %.

Conflict of interest

Authors declared no conflict of interests.

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