EFFECT OF EXTRUSION CONDITIONS ON THE THROUGHPUT OF EXTRUDER FOR THE PRODUCTION OF PINEAPPLE POMACE BASED FISH FEED

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ABSTRACT

Pineapple pomace based extrudates could serve as fish feed with significant health benefits to the fish if supplemented with adequate amounts of other ingredients and mineral-vitamin blends. Pomace is generally disposed during production in juice processing industries and has valuable use in fish production. Response surface methodology was used to examine the extrusion processing effect parameters such as feeding rate (1.28, 1.44 and 1.60 kg min^{-1}), screw speed (305, 355 and 405 rpm), barrel temperature (60, 80 , 100 and 120°C) cutting speed (1300, 1400 and 1500 rpm) and open die hole (50, 75 and 100%) in relation to moisture content of the mash (16, 19 and 22%) with increased pomace inclusion (5-20%) on the throughput of a single screw extruder. Throughput significantly decreased with increased inclusion of pineapple pomace, moisture content, die cutting speed, open surface hole and reduced screw speed. The extruder worked optimally to achieve a throughput of 46.82 kg hr^{-1} at feeding speed (1.60 kg min^{-1}), screw speed (405 rpm), moisture (16.0%), temperature (120°C), cutting speed (1400 rpm), pomace inclusion (5.0%) and open surface (100%). The use of pineapple pomace to produce fish feed and extruder performance is a novel approach with potential to reduce environmental nuisance.

Keywords: Pomace, extrusion, single screw, response surface methodology, feed.

1. INTRODUCTION

Rising demand for quality protein for human consumption can be fulfilled by sustainable aquaculture. However, the industry is experiencing a decline as a result of high production costs caused by high feed costs**.** In order to effectively free aquatic ecosystems, fish farming should be more sustainable, such as an alternative fish feed, without shortage and expensive ingredients (Smith et al., 2010). However, prices for conventional ingredients are on the rise and pose a risk to the environment. Therefore, the future of aquaculture will depend on how well it overcomes this challenge through a sustainable bio-based economy, and incorporation of biological (Bennich and Belyazid, 2017). One of the identified materials that have great potential as a feed source is pineapple pomace (Devi et al., 2016). However, such new concepts must be technically and economically viable in order to succeed in the long term.

The pomace (35% of whole fruit) produced after the processing of pineapple has been causing nuisance to the environment as a result of inappropriate disposal method (Bocco et al., 1998). About 60-75 tons per day of the pomace is generated in a fruit processing plant during one season and 10 to 15 tons per day is generated off-season with cost of disposing the waste estimated to about 237US$ per day (Oduntan and Bamgboye, 2015). Therefore, a way of reducing the nuisance and environmental problems is in its conversion to useful products. This is expected to ameliorate the cost of disposal while adding economic value to the pomace. One promising way of its utilization is in the production of feed for animals. Heuze et al. (2013) reported that pomace has high nutrient digestibility effect in animal models. However, the primary challenges in the aquaculture sector are the process methodology, the poor functionality of the mash, the availability of various anti-nutritional factors and lack of important nutrients. One of the effective conventional technologies of doling out the pineapple pomace into animal feed is extrusion cooking process.

Extrusion is a processing operation that utilizes high temperature, pressure and shear to produce highly-expanded low-density products with unique texture properties, feed conversion, sterilization, palatability, ensuring the availability of nutrients and develop new products (Pardeshi and Chattopadhyay, 2014). Extrusion also leads to extrudates with high durability and water stability, and the process can be adapted to produce floating feed that is more suitable to aquatic species and allows direct determination of feed consumption (Lundblad et al., 2012). It is important to study the extrusion cooking process for optimum conditions for the production of pineapple pomace. The use of a single screw extruder requires the minimization of unnecessary deformation, energy usage, and improved product quality. The throughput of an extruder is directly linked to production capacity (Bereaux et al., 2009). In this work, throughput of the extruder was evaluated at different processing factors. Simple models were also applied in order to predict machine throughput from process parameters using response surface methodology.

2. METHODOLOGY

2.1 Sample Preparation

Wet pineapple pomace sample was obtained from a juice processing plant in Ibadan, Nigeria (Funman Agricultural Products Ind. Ltd, Moor Plantation). The pineapple pomace was dried in a fluidized bed dryer (AS 230, Fexod, Nigeria) at temperature of 65^{o}C and air velocity of 5.0 m s^{-1} in a forced convection thin layer dryer with the loading thickness between 10 - 15 mm (Hosseini Ghaboos et al., 2016). The dried samples were ground to powder through a 0.2 mm screen plate in a disc mill (AS 230, Fexod, Nigeria).

2.2 Feed Blend Formulation

Pomace flour was used to replace wheat bran at various levels (5, 10, 15 and 20%) to produce a formulated, balanced diet catfish feed. Nutrient composition was based on the current data available for feeding catfish (Njieassam, 2016). The formulated feed components (Table 1) were then ground and sieved through a 0.2 mm diameter screen (DS 200, Fedek, Nigeria) to obtain a uniform particle size distribution (Sacilik and Unal., 2005). The composition was mixed by adding water to each formulated blend to increase the initial moisture content (12%) to 16, 19 and 22% for 10 minutes (Oduntan and Bamgboye, 2015) in a batch mixer (Fexod AS 170, Nigeria).

Table 1: Ingredient components in the prepared feed blends

Feed ingredients	Mass of ingredients (g/100g)				
	Control	Blend 1	Blend 2	Blend 3	Blend 4
Groundnut Cake	16	16	18	20	22
Soya Meal	23.7	23.7	21.7	19.7	17.9
Fish Meal (72%)	22	22	22	22	22
Wheat bran	25	20	15	10	5

Corn Flour	5	5	5	5	5
Cassava Flour	5	5	5	5	5
Pineapple Pomace	0	5	10	15	20
DPC	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
Met	0.1	0.1	0.1	0.1	0.1
Vitamin C	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
TOTAL	100	100	100	100	100

2.2 Extrusion processing

Extrusion cooking was performed using a single-screw extruder (Fexod S22C, Nigeria) powered by a 5.15 kW electric motor. The extruder screw speed was monitored with the use of variable transformer (Milan, Italy) and photo/contact tachometer (Taiwan) to achieve the speed range of 0 to 409 rpm. However, the practical ranges of the feeding rate (1.28, 1.44 and 1.60 kg min^{-1}), screw speed (305, 355 and 405 rpm), barrel temperatures (60, 80 , 100 and 120°C) cutting speeds (1300, 1400 and 1500 rpm) and open die hole (50, 75 and 100%) in relation to moisture content of the mash (16, 19 and 22%) with increased pomace inclusion (5-20%) were taken into account in the experimental design (Oduntan and Bamgboye, 2015). The die head was equipped with a probe to monitor the temperature at the center of the product flow. The die had circular holes of 5 mm with a length of 10 mm (L/D of 2.0). Open surface of the die was modified by closing some of the 8 holes on the die. The extrudates were cut at the die exit with three hard knife blades. The products were dried in a fluidized bed (Fexod AS 230, Nigeria) at 85^{o}C. Samples were immediately transferred to thick polyethylene bags and stored at room temperature for further use.

2.3 Measurement of Extruder performance (Throughput)

The throughput of a single-screw extruder is based on the flow of resistance generated by the rotation of the screw and the pressure generated as a result of the constraint of the die. The extrusion throughput was calculated using equation (1) (Bereaux et al*.,* 2009)

$$MFR = M_p/T \qquad (1)$$

where: M_p– average mass of the extrudates collected after extrusion (kg); T– extrusion time (h).

2.4 Statistical analysis

Data were analysed using ANOVA at $\alpha_{0.05}$, while response surface methodology was employed for the sensitivity analysis with the statistical software Design-Expert 11.

3. RESULTS

The throughput of the machine was in the range of 27.99 to 53.58 kgh^{-1}, with the maximum fraction to a minimum of 1.92. "F value adjustment" of 7.14 means the absence of a suitable fit. An F value of 2.80 and R^2 value of 0.9074 can be used to predict the levels of the responses of each factor. The model coefficients of feeding rate (x_1), temperature (x_4) and open surface die (x_7) were positive, indicating that the throughput increased as the factors increased (Equation 2). Among the independent parameters, the pomace inclusion index was significant. A negative coefficient of screw speed (x_2), moisture content (x_3), cutting speed (x_5) and pomace inclusion rate (x_6), indicated a decrease in the throughput as the factor values increased.

The Predictive model for throughput using coded variables is:

$$Y_{THR}= 44.90+1.13\,x_1+3.21\,x_2+0.46\,x_3+0.35x_4-1.12\,x_5-3.86x_6+2.89\,x_7-0.17\,x_1x_2+0.10\,x_1x_3-0.35\,x_1x_4+0.61\,x_1x_5+1.51x_1x_6+1.14x_1x_7+0.35\,x_2x_3+1.05\,x_2x_4+0.43x_2x_5+2.89x_2x_6-0.47\,x_2x_7-0.15x_3x_4+1.20x_3x_5+1.39\,x_3x_6-2.53x_3x_7-1.92x_4x_5-0.69x_4x_6+0.45x_4x_7-1.61x_5x_6+0.39\,x_5x_7+1.69x_6x_7-0.67x_1^2+2.39x_2^2+1.65\,x_3^2-2.41x_4^2+0.58x_5^2-0.11x_6^2-0.96x_7^2 \quad (2)$$

4. Discussion

Analysis of variance showed that the efficiency was significantly based on the linear conditions of extruder screw speed [(SS, $p < 0.05$)], pomace inclusion rate [(PI, $p < 0.05$)] and the open die surface [(OD, $p < 0.05$)] and the screw speed-pomace of inclusion interactions [(SS-PI, $p < 0.05$)]; moisture content-open die surface [(MC-OD, $p<0.05$)]. The pomace inclusion rate affected the throughput, while the temperature, feed rate and cutting speed did not have significant effect on the throughput.

The perturbation chart as shown in Fig. 1 shows the effect of individual factor on throughput. The throughput decreases from 44.76 to 40.93 kg hr^{-1} as the pomace inclusion rate increases from the zero point to the right. Similarly, a decrease in the throughput was observed with respect to the temperature (44.76-42.85 kg hr^{-1}) and cutting speed (44.76-44.36 kg hr^{-1}), which increase during the experiments. On the other hand, the machine's throughput increases sharply from reference point of 44.76 to 50.48 kg hr^{-1} as the screw speed increases. It was observed that the rate of feeding the extruder was low for all runs. This may be due to the design of screw configuration towards the use of pineapple pomace.

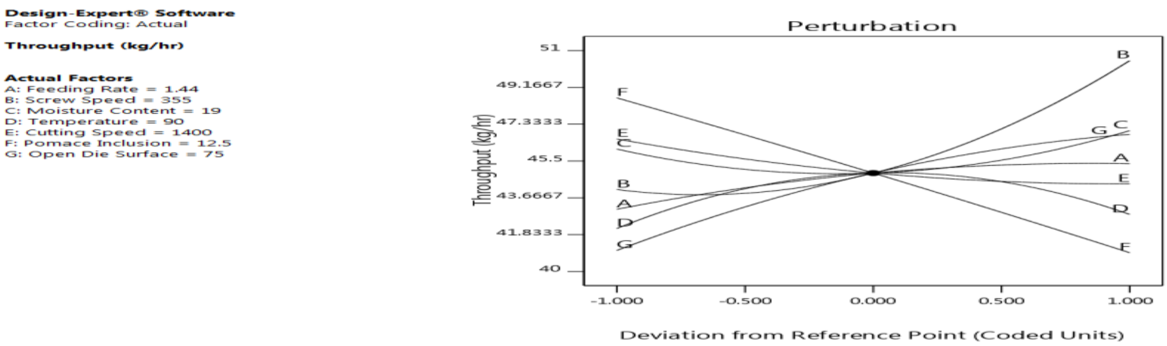

Fig. 1: A perturbation plan for machine Throughput

The effects of the interaction between the variables (pomace and screw speed) for the throughput are shown in Fig. 2. As the screw speed increases to the maximum value with low pomace inclusion, high values of the throughput were recorded. However, with the higher pomace and the minimum operating speed of the screw, the throughput decreases. Therefore, it appears that the throughput in a single-screw extruder depends on the resistance flow generated by the rotation of the screw and the pressure generated as a result of the restraint on the die. Tiwari and Jha, (2017) reported that the flow of resistance during extrusion processes is proportional to the screw speed. In addition, higher screw speeds resulted in higher throughput because greater feed transfer power was required along the extruder barrel (Rosentrater et al., 2009; Oduntan et al., 2014).

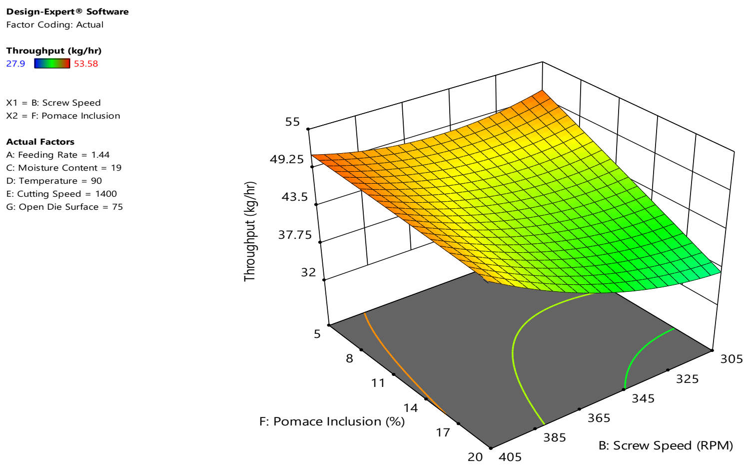

Fig. 2: Effect of pomace inclusion and screw speed on throughput

Fig. 3 shows that as the moisture level increases and the number of open die surfaces increases, the throughput increases. At the maximum openings of the die with the lowest moisture content, the highest throughput was observed. A similar phenomenon was observed by Fallahi et al., 2013 on the influence of moisture content on throughput. It was noticed that the increase in the moisture content in the mash caused a decrease in the throughput with the highest (100%) opening of the number of die holes. Chevanan et al. (2008) and Oduntan et al. (2014) reported similar capacity results with respect to moisture content variations.

The optimal conditions for pineapple pomace based fish feed specified limits, was obtained at a feeding rate of 1.12 kg min^{-1}; screw speed, 305rpm; moisture, 19.06%; temperature, 60°C; cutting speed, 1500 rpm; pomace inclusion rate, 5% and open surface die, 64.84% with a desirability of 0.67. At these optimised conditions, a predicted throughput was 46.82 kg hr^{-1}.

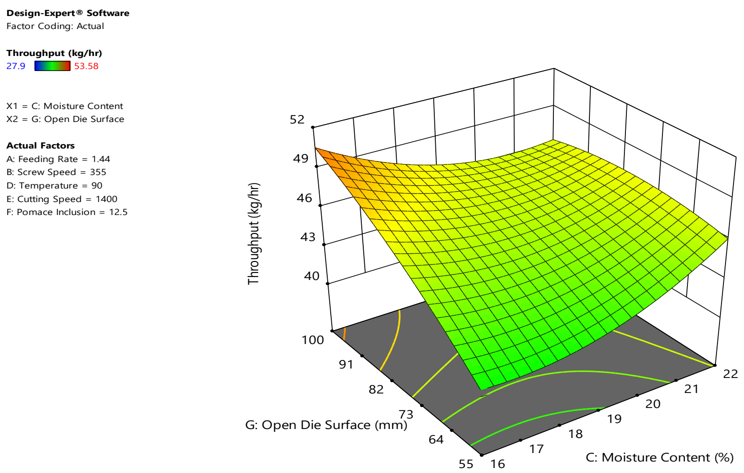

Fig. 3: Effect of open surface die (5mm) and moisture content on throughput

5.Conclusion

Extrusion process is attractive options for converting pineapple pomace into useful products such as fish feed with potential to reduce nuisance to the environment. The result shows that the screw speed, pomace inclusion speed and open die surface were extrusion variables that were found to affect the performance of the extruder. Understanding the effect of process variables with the use of waste on quality parameters of fish feed extrudates is important to facilitate industrial application of this technology.

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