



Performance Evaluation of Pelletizing Machine

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Abstract:

A feed pelletizing machine was modified and incorporated with an easily detachable die plate (4mm, 6mm and 8mm) capable of extruding different sized feed. Performance evaluation of the machine was carried out using a non-conventional feed and with a moisture content of 15% wet basis. Three processing parameters (die size, pulley diameter and operating time) at three levels were considered. The performance indices considered in the evaluation of the pelletizer were pelleting efficiency and throughput capacity. The maximum machine efficiency obtained was 80.0% at 6mm die size, 6min machine operating time and 250mm pulley diameter. While, the minimum value of 40% was obtained at 8mm, 4min and 150mm, die size, machine operating time, and pulley diameter respectively. The effects of the processing variables were studied using a regression model and it was revealed that the process variables considered had a significant effect ($p \leq 0.05$) on the machine efficiency and throughput capacity. The study concludes that the pelletizing machine efficiency obtained increased as the dependent variables that is, die size, pulley diameter and time increased and vice versa. The study recommends that further operating parameters such as moisture content of feed, binding ratio and machine operating speed should be considered

Keywords: Pelleting; Efficiency; Throughput capacity; Performance evaluation; operating time; die size; pulley diameter.

Introduction

Feeding livestock with pellets is advantageous to the livestock and the farmer as it is economical and supplies the required nutrients to the livestock. Pelleted feeds yield positive effects on growth of livestock fish inclusive and production efficiency (Greenwood *et al.*, 2004). The processing methods of fish feed pelleting include sourcing of feeds, grinding and mixing with other materials to obtain desired ration, pelleting with the addition of water or preferably steam, drying, cooling and storing which is very crucial as it determines bioavailability of nutrients, feed acceptability, palatability and durability which ultimately reflects in the performance of fish (Gabriel *et al.*, 2007). The raw materials formulated in mixing of these feeds were mostly imported (BAS, 2009). This led to the high cost of commercial feeds in the country. This high cost of input has led to formulation of feeds traditionally. (Cabarles and Dusan, 2006). Traditional method of processing fish feed is extremely strenuous; causes great discomfort to the operators and cannot predict grinding time. These result in the production of low quality feeds (Malgwi *et al.*, 2020). The modern method is by the use of pelletizing machine.

Pelletizing machine is an equipment used for making mainly powdery materials and some solid of variable sizes into pellets (Ikebudu, 2015). Pelletizing machine is a machine that can be used to create and extrude desired shapes of pellets from a mixture of components. It consists of a screw pump similar to a screw press or screw conveyor in which feed is compressed and worked to form a semi-solid mass (Ikedudu *et al.*, 2015). Pelleting machines can perform the function of moulding of feed meals like soft capsules for animals (Fasakin, 2005). The factors that most influence the nature of the pelletized product are basically classified into operating conditions (temperature, pressure, diameter of the die aperture, operating speed and the share rate) of the machine and the rheological properties (moisture content and the physical state) of the feed amongst others (Okewole and Igbeka, 2016). Several published studies have shown that moisture content and die sizes of the pellets are significantly affected by the durability of the pellets (Nelson, 2002; McMullen *et al.*, 2005). However, the feed pelleting machines are not favourable to the local farmers due to its high cost (Ikedudu *et al.*, 2015). Therefore, this research work is to modify an existing local fish feed pelleting machine and investigate the effect of some

operating parameters including (die diameter, operating time and operating speed) on evaluation parameters for producing pellets from a pelletizing machine. The main aim of this study is to carry out performance evaluation of pelletizing machine.

Materials and Methods

Sample Sourcing and Preparation

Compounded fish feed was prepared by locally sourced materials. The ingredients were soya bean meal, groundnut cake, maize, fishmeal, palm kernel, cottonseed, leguminous crops, green plant meals, and premix. Some starch (garri) and little water that serve as binders were added to the compounded feed, and it was thoroughly mixed manually and processed to produce fish feed pellet as in Plate 1a and b.



(a)



(b)

Plate 1: (a) Pellet feed production, (b) pellet feed

Test Procedure

The compounded feed mix was fed through the machine hopper after the machine is switch on. The pelletized feed was collected through the outlet and observed in case the machine required further modification or adjustment. Different die size, operating time and pulley diameter were used as independent variables while machine efficiency and throughput

capacity were observed as dependent variables using Design Expert 12.0 software package.

Performance Analysis

To evaluate the performance of the pelleting machine, three factors (Die size, pulley diameter and machine operating time) at three levels was designed with the aid of Design expert software. The design consisted of seventeen (17) experiments conducted in triplicates with two independent factors (die size and operating speed).

Pelleting Efficiency (P.E)

It is the ratio of the quantity of actual feed pellet obtained at the main die orifice to the total feed input per unit time (Ojomo *et al.*, 2010; Davies *et al.*, 2011). This was determined using the following Equation 1.

$$P.E = \frac{W_p}{W_m} \times 100 \quad (1)$$

where:

W_p is the quantity of actual feed pellet (kg).

W_m is the total feed input mass (kg).

Throughput Capacity (T.C.)

This is the ratio of the quantity of actual feed pelleted to the time taken (Ojomo *et al.*, 2010). The weight of pellets was measured by weighing a sample of pellets after the pelleting process with respect to the time taken to produce that sample using the stopwatch. The throughput capacity was therefore estimated as the weight of the sampled pellets per time of production of a particular sample as defined in Equation 2.

$$T.C = \frac{W_p}{T} \text{ (kg/h)} \quad (2)$$

where:

W_p = the weight of the pellets (kg)

T = the time taken to pelletize the specified feed in hours.

Statistical Analysis

The data obtained from the performance analysis of the pelleting machine was studied to know if there are any significant differences in the fish feed production rate (kg) of the pelletizing machine between the three pellet die size, pulley diameter and operating speed. The data was subjected to ANOVA and the effect of the responses was determined using regression model. The P-values was used as a tool to check the level of significance ($p \leq 0.05$) of each of the coefficients, which, in turn are necessary to understand the pattern of the mutual interactions between the test variables.



Results and discussion

Results

The results of design matrix for the performance evaluation of the pelletizing machine is presented in Table 1, while the ANOVA results for the machine efficiency and throughput capacity are as presented in Tables 2 and 3 respectively.

Table 1: Design Layout and Results for Machine Efficiency and Throughput Capacity

St	Ru	Factor 1	Factor 2	Factor 3	Response 1	Response 2
d	n	A:Die Size	B:Time	C:Diameter	Efficiency	Throughput Capacity
		Mm	Min	Mm	%	kg/hr
2	1	8	2	200	66.7	30
3	2	4	6	200	47	18
13	3	6	4	200	75.3	33.9
8	4	8	4	250	73.7	33.1
17	5	6	4	200	75.3	33.9
10	6	6	6	150	46.7	14
15	7	6	4	200	75.3	33.9
6	8	8	4	150	40	18.15
9	9	6	2	150	43.3	19.5
7	10	4	4	250	43	17
4	11	8	6	200	77.5	31
12	12	6	6	250	80	24
1	13	4	2	200	42	15
16	14	6	4	200	75.3	33.9
11	15	6	2	250	56.7	25.5
5	16	4	4	150	45	16.5
14	17	6	4	200	75.3	33.9

Table 2: ANOVA for Machine Efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3811.92	9	423.55	19.54	0.0004 significant
A-Die Size	818.10	1	818.10	37.74	0.0005
B-Time	225.78	1	225.78	10.41	0.0145
C-Diameter	768.32	1	768.32	35.44	0.0006
AB	8.41	1	8.41	0.3879	0.5531
AC	318.62	1	318.62	14.70	0.0064
BC	99.00	1	99.00	4.57	0.0699
A ²	569.01	1	569.01	26.25	0.0014
B ²	121.64	1	121.64	5.61	0.0497
C ²	739.21	1	739.21	34.10	0.0006

Residual	151.76	7	21.68
Lack of Fit	151.76	3	50.59
Pure Error	0.0000	4	0.0000
Cor Total	3963.68	16	

Statistical Parameters:

$R^2 = 0.9617$ Adj $R^2 = 0.9125$

Pre $R^2 = 0.3874$ Adeq Precision = 11.1520

Table 3: ANOVA for Throughput Capacity

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	976.74	9	108.53	26.85	0.0001 Significant
A-Die Size	261.63	1	261.63	64.72	< 0.0001
B-Time	1.12	1	1.12	0.2783	0.6141
C-Diameter	123.64	1	123.64	30.59	0.0009
AB	1.0000	1	1.0000	0.2474	0.6342
AC	52.20	1	52.20	12.91	0.0088
BC	4.00	1	4.00	0.9896	0.3530
A ²	104.48	1	104.48	25.85	0.0014
B ²	123.63	1	123.63	30.59	0.0009
C ²	251.67	1	251.67	62.26	< 0.0001
Residual	28.30	7	4.04		
Lack of Fit	28.30	3	9.43		
Pure Error	0.0000	4	0.0000		
Cor Total	1005.03	16			

Statistical Parameters: $R^2 = 0.9718$ Adj $R^2 = 0.9356$

Pre $R^2 = 0.5495$ Adeq Precision = 12.5162

Effects of Processing Variables on the Efficiency and Throughput Capacity of Pelletizing Machine

The results show the effects of die size, pulley diameter and operating time on the pelletizing machine efficiency and throughput capacity.

Effects of processing variables on pelletizing machine efficiency

The design matrix and results of the machine efficiency for fish feed is presented in Table 1. The software presented a model and regression analysis to correlate the machine efficiency with the independent variables of die size, pulley diameter and time considered for the study using a second order polynomial equation for the fish feed as presented in Equation 3 which shows A, B, C, AB, AC and BC as significant model terms, having synergetic effect on machine efficiency while A², B² and C² antagonistic effect.

$$\begin{aligned} \text{Eff} (\%) = & 187.38750 + 20.63125A + \\ & 1.28125B + 1.58150C + 0.362500AB + \\ & 0.089250AC + 0.049750BC - 2.90625A^2 - \\ & 1.3437B^2 - 0.005300C^2 \quad (3) \end{aligned}$$

where:

Eff = Pelletizing Machine Efficiency (%)

A = Die Size (mm)

B = Time (min)

C = Pulley Diameter (mm)

The ANOVA results and statistical parameters of the analysis which describes the relationship between the independent variables and the dependent variable, machine efficiency is as presented in Table 2. The probability of the P-value and F-value of 0.0004 and 19.54 of fish feed pelletizing machine efficiency indicates that the model suggested by the software for the material was significant at 95% confidence level. The R^2 is 0.9617 meaning 96.17% of the variability can be accounted for and showing the regression model was satisfactory for the prediction of the machine efficiency. The ANOVA results of the model terms presented in Table 2 shows A, B, C, AC, A^2 , B^2 and C^2 are significant model terms.

The three-dimensional surface graph (3D) in Figures 1 a, b and c respectively show the effect of die size, operating time and pulley size on the machine efficiency. The combined effect of die size and time shows in figure 1a that machine efficiency increased with increase in die size and time up to a certain level before decreasing. The maximum and minimum machine efficiency was obtained to be 80.0% and 40.0% at 6mm, 6min and 8mm and 4min respectively. While it is shown in figure 1b for the combined effect of die size and pulley diameter shows that machine efficiency of 80.0 and 40% were obtained at 6mm and 200mm and 8mm and 150mm respectively. Figure 1c shows the combined effect of pulley diameter and time on the machine efficiency which results to increase in pulley diameter and time as machine efficiency increased and vice versa. The similar increase in machine efficiency of the pelletizing fish feed from 40-80% at 4-8mm die size and 150mm-200mm was reported by Okolie *et al*, (2012).

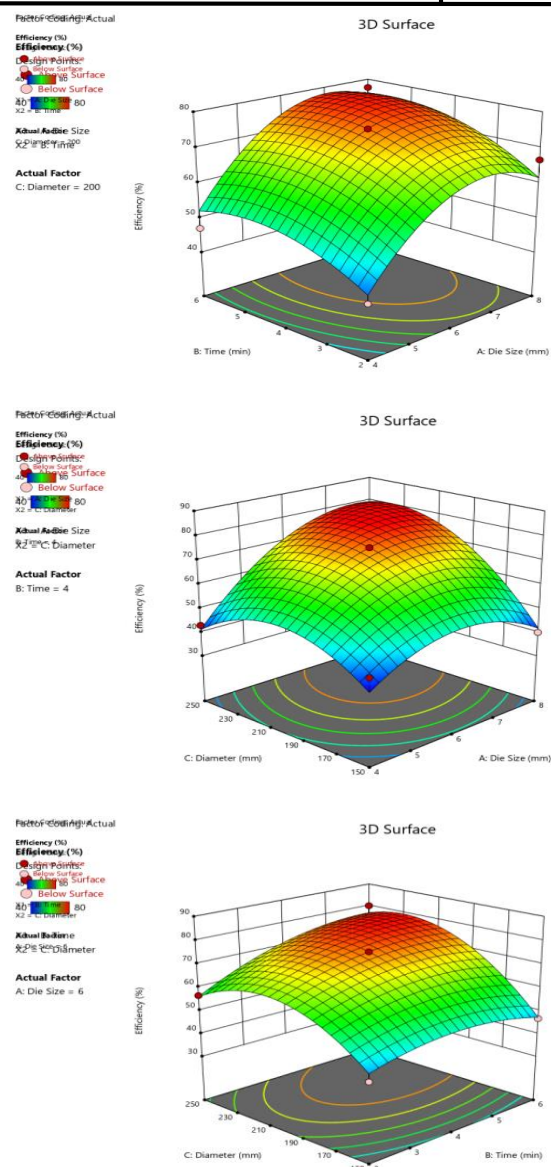


Figure 1: Response surface of machine efficiency as influenced by
(a) die size and operating time, (b) die size and pulley diameter, (c) operating time and pulley diameter

Effects of processing variables on pelletizing machine throughput capacity

The design matrix and results of the throughput capacity for fish feed is presented in Table 1. The software presented a model and regression analysis to correlate the throughput capacity with the independent variables of die size, pulley diameter and time considered for the study using a second order polynomial equation for the fish feed as presented in Equation 4 which shows A, C, AC, BC having significant terms which have synergetic effect and B, AB, A^2 , B^2 , C^2 having antagonistic effect on the pelletizing machine throughput capacity.

$$TC(kg/hr) = 33.90 + 5.72A - 0.3750B + 3.93C - 0.05000AB + 3.61AC + 1.00BC - 4.98A^2 - 5.428B^2 - 7.73C^2 \quad (4)$$

where:

TC = Throughput capacity, kg/hr

A = Die size, mm

B = Time, min

C = Pulley diameter, mm

The ANOVA results and statistical parameters of the analysis describe the relationship between the independent variables and the dependent variable machine throughput capacity is as presented in Table 3. The probability of the P-value and F-value of 0.0001 and 26.85 of the machine throughput capacity shows that the model suggested by the software was significant at 95% confidence level. The R^2 is 0.9718 meaning 97.18% of the variability can be accounted for and showing the regression model satisfactory for the prediction of the machine throughput capacity. The ANOVA results of the model terms presented in Table 4.3 shows A, C, AC, A², B² and C² are significant model terms.

The 3D surface graph in figures 2a, b and c respectively show the effects of die size, pulley diameter and time shown in figures 2a, 2b and 2c that throughput capacity increased with increase in die size, pulley diameter and time and vice versa. The maximum and minimum throughput capacity of 33.9 and 14kg/hr were obtained at 6mm, 4min, and 6mm, 6min, respectively. Diarra *et al.* (2015) obtained similar results. Figure 2b shows the combined effect of die size and pulley diameter, the maximum machine throughput capacities were obtained at 6mm, 200mm and 6mm, 150mm, respectively. Figure 2c shows that throughput capacity increased as pulley diameter and time increased up to a certain level before decreasing, this was also reported by Ikebudu *et al.*, (2015).

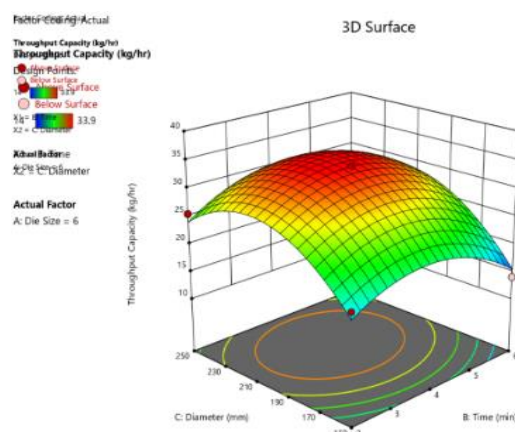
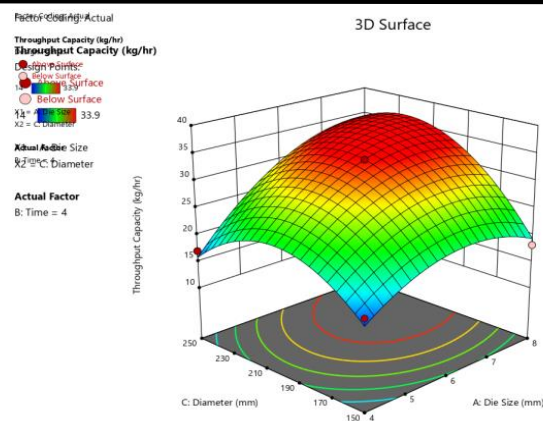
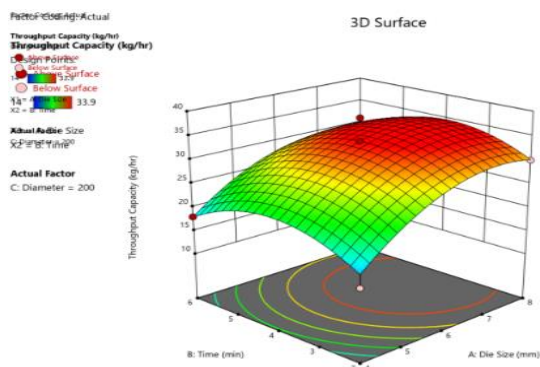


Figure 2: Response surface of throughput capacity as influence by

(a) die size and time, (b) die size and pulley diameter, (c) time and pulley diameter

Conclusions

The pelletizing machine efficiency obtained increased as the dependent variables that is die size, pulley diameter and time are increased and vice versa. Also, the pelletizing machine throughput capacity is increased as die size, pulley diameter and time increased and vice versa. That die size and pulley diameter gives more synergetic effects on the two responses (machine efficiency and throughput capacity).

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