Effect of some operating parameters on the performance of a pelleting press

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Abstract: One of the major challenges of fish pellets production at the micro and small scale level is the principal complement of equipment necessary for the local manufacture of the same. Imported fish pellets are quite expensive and unaffordable for the average fish farmer. Hence, the need to be able to produce fish feed at a lower cost yet achieving the objective of quantity and quality expected of pelleted feeds are paramount to the viability of the enterprise.

The aim of the study was to investigate the effects of some operating parameters (moisture content of the compounded feed, die speed of the press, and the feed rate) on the pelleting efficiency, throughput capacity, pellet durability and pellet bulk density and to optimise the conditions. Three moisture content levels (M_1= 13, M_2= 20 and M_3 = 25% wet basis) of the compounded feed were used. For each of the moisture contents, two feed rates (Q_1= 500, Q_2= 350 kg/hr); and two die speeds (V_1=200, and V_2=250 r/min) were used for a die hole size of 4 mm. The effect of the independent parameters was significant for pellet efficiency, throughput capacity, pellet durability and pellet bulk density with R_2 values of 0.9399, 0.9612, 0.8806 and 0.8977 respectively. This shows that the coefficient of determination is of positive correlation as determined from the ANOVA (Analysis of Variance) and the model equation. ANOVA was performed to check the adequacy of the fitted models. The response surface plots showing the interaction of variables were developed in Design-Expert 6.0.6 for every response, linear variables were found more significant than quadratic variables. Optimum conditions for maximum pellet efficiency, throughput capacity, pellet durability and bulk density corresponds to moisture content 25%, feed rate 499.99 kg/hr, speed 250 r/min with the desirability of 0.986. At this condition, pellet efficiency, throughput capacity, pellet durability and pellet bulk density were recorded as 95.7893%, 166.276 kg/hr, 98.0435% 0.846702 g/cm^3 respectively.

Keywords: pelleting press, efficiency, durability, throughput capacity, bulk density, Response Surface Methodology (RSM), evaluation

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1 Introduction

Pelleted feeds have been defined as agglomerated feeds formed by extruding individual ingredients or mixtures by compacting and forcing through die openings by any mechanical process. Pelleted feeds are easier to handle; more palatable and usually result in improved feeding when compared to the unpelleted feeds. Pelleted feeds yield positive effects on growth of livestock fish inclusive and production efficiency (Kilburn and Edwards, 2001; Greenwood et al., 2004; McKinney and Teeter, 2004).

Generally, the processing methods of fish feed pelleting include sourcing of feeds, grinding 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).

According to Vijayagopal (2004), the factors that most influence the nature of the pelletized product are basically classified into two most which are the operating conditions of the machine and the rheological properties of

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the food amongst others, some of which are elaborated below:

a) The operating condition of the machine such as the temperature, pressure, diameter of the die aperture and the share rate;

b) The rheological properties of the food such as moisture content and the physical state;

c) The materials and their chemical composition, particularly the amount and type of starches, protein and fats;

d) Leakage flow, which is similar to pressure flow and is driven by a pressure gradient;

e) This flow occurs in the clearance between the screw flights and the barrel and within any slot in the barrel wall or surfaces. Leakage flow reduces the machine output.

Response Surface Methodology (RSM) has been successfully used to model and optimize biochemical and biotechnological process related to food systems. The main advantage of RSM enables the evaluation of the effects of several process variables and their interactions on response variables. RSM is a collection of statistical and mathematical techniques that has been successfully used for developing, improving and optimizing processes (Myers and Montgomery, 2002). It is faster and more informative than the classical one variable-at-a-time approach or the use of full factorial designs (Ozdemir et al., 2008). RSM is usually applied following a set of design experiments, which have the purpose of screening out the important factors. The primary purpose of the RSM methodology is to find the optimum settings for the factors that influence the response.

The possibility and potentials inherent in the production of pellets for animal feed have not been fully realized and one of the major challenges is the principal complement of equipment necessary for the local manufacture of the same. Imported fish pellets are quite expensive and unaffordable for the average fish farmer. Hence, the need to be able to produce fish feed at a lower cost yet achieving the objective of quantity and quality pelleted feeds are paramount to the viability of the enterprise.

The main objective of this research work is to investigate the effect of some operating parameters including moisture content, die speed and feed rate on evaluation parameters for producing pellets from a vertical shaft pelleting machine. This is essentially based on previous studies of Ojomo et al. (2010) and Davies et al. (2011) on locally fabricated horizontal pelleting press that indicated the importance of these parameters. However, there are different types of pelleting presses, namely: piston and molding presses, tableting presses, roll presses, pellet mills, screw extruders (Perry and Green 1999). The study will enable small holder local pellet producers from fish feed that is compounded from the various ingredients as indicated in Table 1 to produce pellets through the right combination of operating parameters.

Table 1 Compounded feed

Raw materials	Qty, kg
Maize	7.0
Wheat offal	5.0
Soybean cake	15.0
Groundnut cake	20.0
Full fat soya	10.0
Limestone	2.0
Bone meal	1.0
Fish meal 72%	25.0
Premix	0.5
Salt	0.3
Palm oil	4.5
Gelatinised cassava starch	10

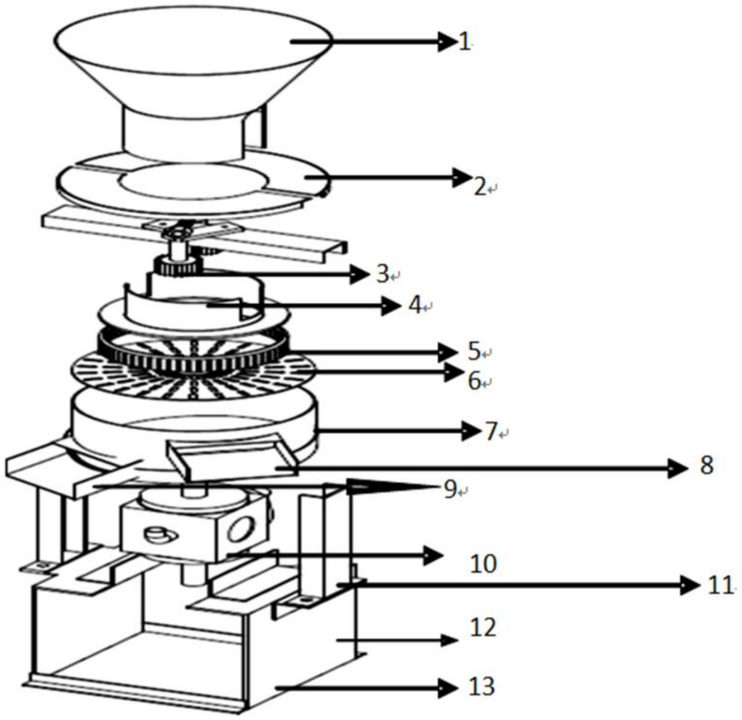
Source: Novus Aquaculture, 2014

2 Materials and methods

2.1 Materials

The materials include components of the fish feed, namely; maize, wheat offal, soybean cake, groundnut cake, full fat soya, limestone, bone meal, fish meal, premix, salt palm oil, and gelatinised starch as represented in Table 1. The devices required for the experiment measurements include: digital tachometer, moisture meter, stop watch, and vernier calliper, tumble box, and the press. The Pelleting Press comprises of:

- the pelleting press comprises of a hopper in form of a conical frustum.
- the pressure devices which comprise the rollers, the bolts, vertical transmission shaft, die (rotor speed and diameter).
- the speed is controlled by the introduction of a right angled speed reduction gear assembly of about 1:2 to appropriately reduce the speed to the desired range.
- other parts are the rollers' housing/ casing, discharge outlet for the pellets and unpelleted mash, limbs/stand, bolts and nuts to enhance fastenings, etc. The view of the machine is shown in Figure 1.



1	Hopper
2	Lid of extruding chamber
3	Rollers
4	Roller housing
5	Die
6	Perforated screen
7	Outer enclosure
8	Pellets discharge chute
9	Unpelleted discharge chute
10	Gear
11	Side limb
12	Gear sit
13	Base limb

Figure 1 Pelleting press

2.2 Responses

2.2.1 Pelleting efficiency (P.E)

It is ratio of the quantity of actual feed pelleted obtained at the main die orifice to the total feed input per unit time (Ojomo et al., 2010; Mansour, 2007; Davies et al., 2011). This was determined using the following Equation (1).

$$\text{P.E.} = \frac{Wp}{Wm} \times 100\ (\%) \qquad (1)$$

Where; W_p is the quantity of actual feed pelleted, kg; and W_m is the total feed input mass, kg.

2.2.2 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 stop watch. 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).

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

Where; W_p is the weight of the pellets, kg; and T is the time taken to pelletize the specified feed in hours.

2.2.3 Pellet durability

Pellet durability fish feed pellets can be described as the ability of pellets to withstand destructive loads and frictional forces during handling and transport. According to ASABE (ASAE S269.4 DEC1991, R2007), the pellet durability was therefore determined as follows; 500 g of pellets placed in the tumbling box device for tumbling up to 10 minutes at 50 r/min after which the broken and cracked pellets were separated and the weight determined. The durability therefore was calculated using the following relation:

$$\text{Pellet Durability} = \frac{Wa}{Wb} \times 100(\%) \quad (3)$$

Where; W_a is the pellets mass after shaker treatment, g; and

W_b is the pellets mass before shaker treatment, g.

2.2.4 Pellet bulk density (PBD)

The pellet bulk density is the degree of compaction of the pellets per unit volume. It is also defined as the ratio of the mass of the extrudates (g) occupying a given bulk volume to the volume of the bulk (cm^3) according to the method recommended by USDA (1999).

$$\text{Pellet Bulk Density } PBD = W_d/V_d\ (\text{g/cm}^3) \quad (4)$$

Where; W_d is the pelleting mass, g; and V_d is the pellets sample volume, cm^3.

Pellet bulk density was determined using an 80 mL cylindrical container. The empty cylindrical container was weighed; pellets were sifted to remove any fines, poured into the cylinder, and levelled by striking off the overflow using the edge of a ruler and the weight was taken again. The weight of the pellets is weight of cylinder with pellets minus weight of empty cylinder. The mass was then recorded and density determined.

2.3 Experimental design and statistics

In general, performance evaluation of the press influenced by some parameters such as moisture content, feed rates and die speeds. Therefore, the independent variables were three moisture content levels (M_1= 13, M_2= 20 and M_3 = 25% wet basis). This is to adequately represent the moisture levels across the possible range of pelleting for the pelleting machine as represented by Vijayagopal (2004) and measured by the moisture meter of the compounded feed. Feed rates of Q1; 500 and Q2; 350 kg/hr and the die speeds of V_1; 200 and V_2; 250 r/min. The range of this moisture levels and values were determined based on review of literature by (Kholief, 1996) and (Mohammad et. al., 2010).

The Response Surface Methodology (RSM) was employed to establish the relationship between the response functions and the process variables. The design consisted of 12 experiments conducted in triplicates (Table 2) with three independent factors (Moisture Content, Die speed and Feed rate).

Table 2 Number of experiments conducted

Number of Experiments	Moisture Content (A)	Feed Rate (B)	Die Speed (C)	Replicates 1	2	3
1.	A_1	B_1	C_1	N_1	N_2	N_3
2.	A_1	B_1	C_2	N_1	N_2	N_3
3.	A_1	B_2	C_1	N_1	N_2	N_3
4.	A_1	B_2	C_2	N_1	N_2	N_3
5.	A_2	B_1	C_1	N_1	N_2,	N_3
6.	A_2	B_1	C_2	N_1	N_2	N_3
7.	A_2	B_2	C_1	N_1	N_2	N_3
8.	A_2	B_2	C_2	N_1	N_2	N_3
9.	A_3	B_1	C_1	N_1	N_2,	N_3
10.	A_3	B_1	C_2	N_1	N_2	N_3
11.	A_3	B_2	C_1	N_1	N_2	N_3
12.	A_3	B_2	C_2	N_1	N_2	N_3

The design expert software was used to generate response surfaces plots. The data were subjected to ANOVA and the effect of the responses was determined at linear, and two factor interactive levels. The P values were used as a tool to check the significance of each of the coefficients, which, in turn are necessary to understand the pattern of the mutual interactions between the test variables. Historical data of Response Surface Methodology (RSM) was used to understand the interactions of independent variables and to derive the optimum conditions of the responses. For the purpose of the analysis, the level of significance was fixed at 5% (p<0.5).

3 Results and discussion

3.1 Results

The fitness and adequacy of the model was judged by the coefficient of determination (R^2) and lack-of-fit. R^2, which can be defined as the ratio of the explained variation to the total variation is a measure of the degree of fit. The closer the R^2 value to unity, the better the empirical model fits the actual data. R^2 values of 0.9399, 0.9612, 0.8806 and 0.8977 represent the coefficient of determination for pellet efficiency, throughput capacity, pellet durability and pellet bulk density respectively.

3.2 Pellet efficiency

The results is as represented below in Table 3

Table 3: Results for pellet efficiency

A, %	B, kg/hr	C, r/min	PE, %
13	500	250	37.5
13	350	250	35.0
13	500	200	40.0
13	350	200	41.7
20	500	250	79.2
20	350	250	80.8
20	500	200	76.7
20	350	200	76.7
25	500	250	95.0
25	350	250	89.3
25	500	200	93.3
25	350	200	89.3

Note: A= moisture content, B= feed rate, C= shaft speed, and PE= pellet efficiency.

It was observed from the performance evaluation and as shown in Table 2 and Figures 2a and 2b that the pellet efficiency increased with the increase in moisture content considerably at the speed of 200 r/min and 250 r/min from 13% to 25% for both 500 kg/hr and 350 kg/hr. This was in line with the observation of Linko et al. (1981); Ojomo et al. (2010) that there is always high temperature rise inside the barrel due to the shear and friction generated inside the barrel; the presence of water in the feed promotes gelatinisation of starch components and stretching of expandable feed components to produce pellets.

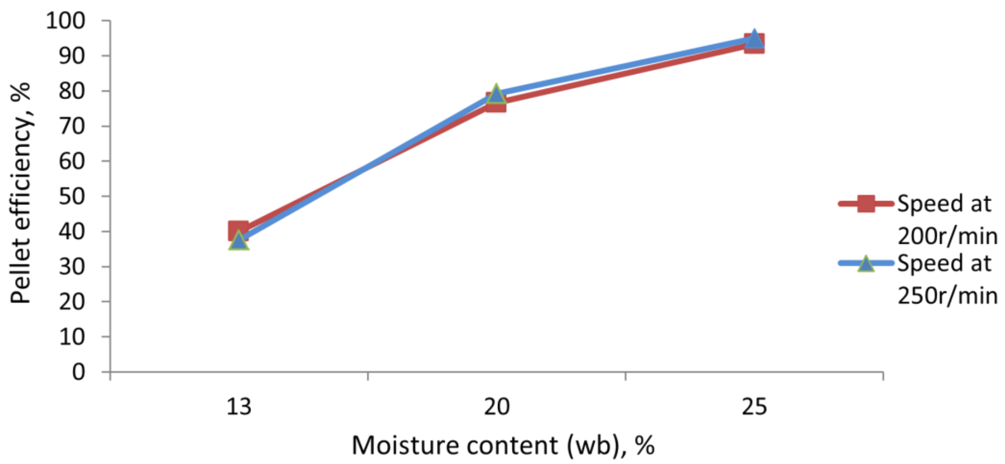


Figure 2a Pelleting efficiency for 500 kg/hr feed rate

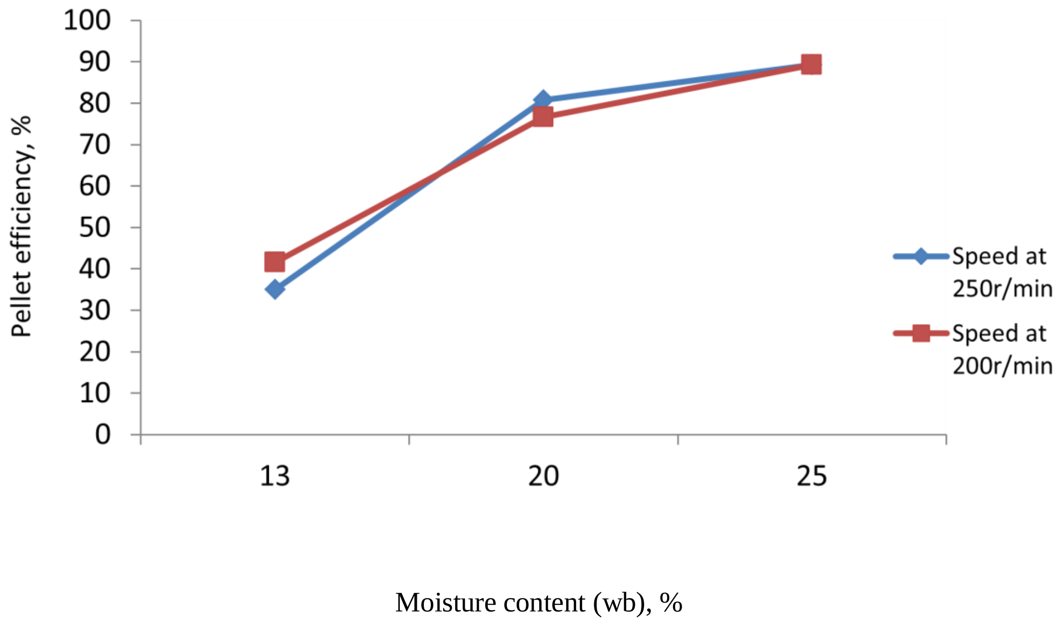


Figure 2b Pelleting Efficiency for 350 kg/hr feed rate

The equation to predict the efficiency of the machine for pellet efficiency is:

$$PE = -21.282 + 4.514 \times A + 9.815E-003 \times B - 2.778E-003 \times C \quad (5)$$

R^2= 0.9399

where, A represents moisture content, %; B is the feed rate, kg/hr; and C is the speed, r/min.

3.3 Throughput capacity

The results are as presented in Table 4

Table 4 Results for throughput capacity

A, %	B, kg/hr	C, r/min	TC, kg/hr
13	500	250	76.9
13	350	250	64.3
13	500	200	71.7
13	350	200	73.2
20	500	250	125.7
20	350	250	116.2
20	500	200	112.3
20	350	200	108.3
25	500	250	168.2
25	350	250	153.2
25	500	200	139.6
25	350	200	142.3

Note: A=moisture content, B=feed rate, C=shaft speed, and TC= throughput capacity.

The results as displayed in Figure 2 indicates the increase in throughput as speed, moisture content and feed rate increases. This is further corroborated in Figures 3a and 3b. The throughput capacity was observed to follow a similar pattern as the pellet efficiency as the throughput capacity increases with the increase in moisture content considerably at the speed of 200 and 250 r/min from 13% to 25% for both 500 kg/hr and 350 kg/hr. This is because the increase in speed of the die and moisture content of the feed promotes pellet formation by increase in frictional force within the barrel that translates to increase binding forces within the interstices of the feed and faster passage through the die of the pelletizer. The results corroborate the observation of Yacu (1995) which stated that the screw speed is a factor in determining the maximum volumetric output of the pelletizer, and is one reason why most pelletizer manufacturers design machines to run at maximum speed. The only argument against this is the increase in wear rate of the mechanical components of the machine (Ojomo et al., 2010).

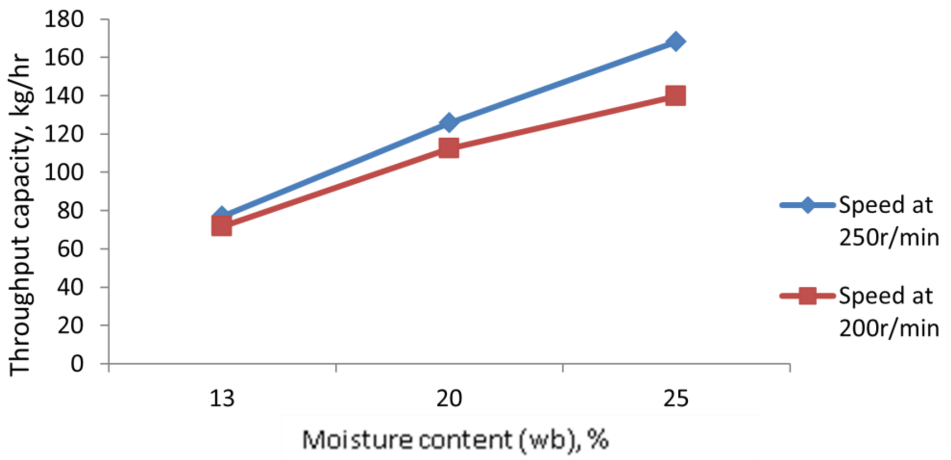


Figure 3a Throughput Capacity for 500 kg/hr feed rate

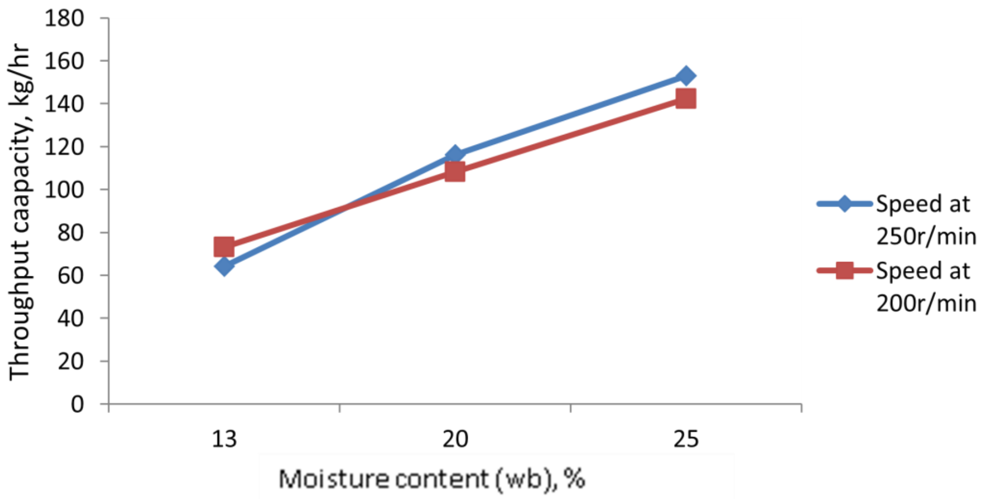


Figure 3b Throughput capacity for 350 kg/hr feed rate

$$TC = +243.625 - 1.656 \times A - 0.342 \times B - 1.211 \times C + 4.080E-004 \times AB + 0.036AC + 1.668E-003BC \quad (6)$$

R^2 = 0.9612

Where, A represents moisture content, %; B is the feed rate, kg/hr; and C is the speed, r/min.

3.4 Pellet durability

The result is as presented in Table 5.

Table 5 Results for pellet durability

A, %	B, kg/hr	C, r/min	PD, %
13	500	250	47.8
13	350	250	52.4
13	500	200	47.8
13	350	200	44.0
20	500	250	86.3
20	350	250	84.6
20	500	200	87.0
20	350	200	85.6
25	500	250	91.6
25	350	250	94.8
25	500	200	92.2
25	350	200	96.3

Note: A= moisture content, B= feed rate, C= shaft speed, and PD= pellet durability.

The figure as shown in Figures 4a and 4b showed a general increase of pellet durability with the increase in moisture content for both 500 kg/hr and 350 kg/hr feed rates which resulted in the highest value of pellet durability at 25% moisture content and the lowest at 13% moisture content. In the case of 500 kg/hr feed rate (Figure 4b) the die speed of 250 r/min and 200 r/min had very close values as is shown in Figure 4a. This corroborates findings by Fallahi et al. (2013) where increase in moisture content had an increase in Pellet Durability Index and increase in speed had very little decrease (difference of 0.42) in pellet durability between 350 r/min and 400 r/min. The increase in moisture content enhances the binding strength of the feed as a result of frictional force generated while the feed is forced through the die by the rollers.

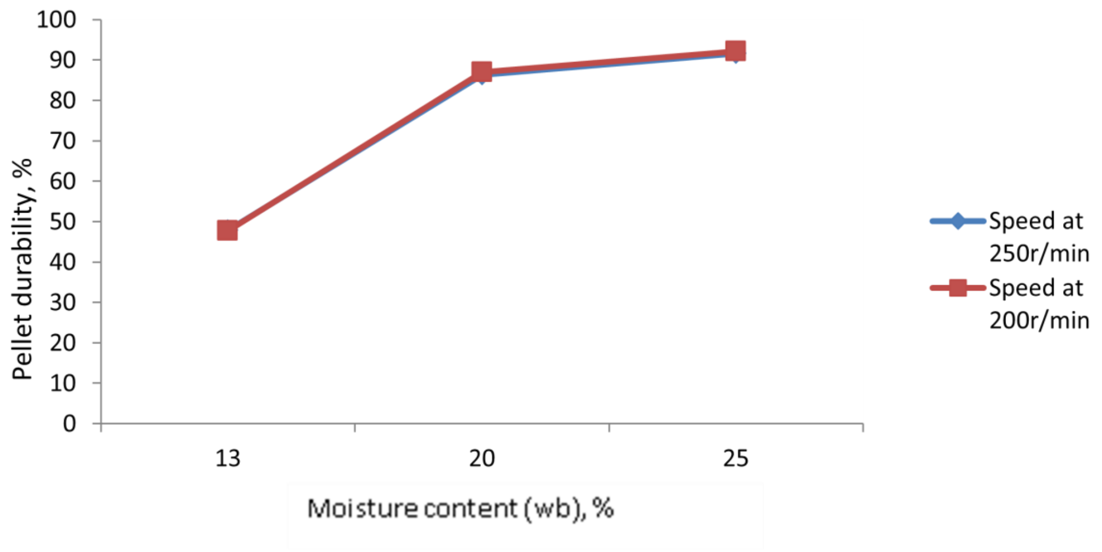


Figure 4a Pellet durability for 500kg/hr feed rate

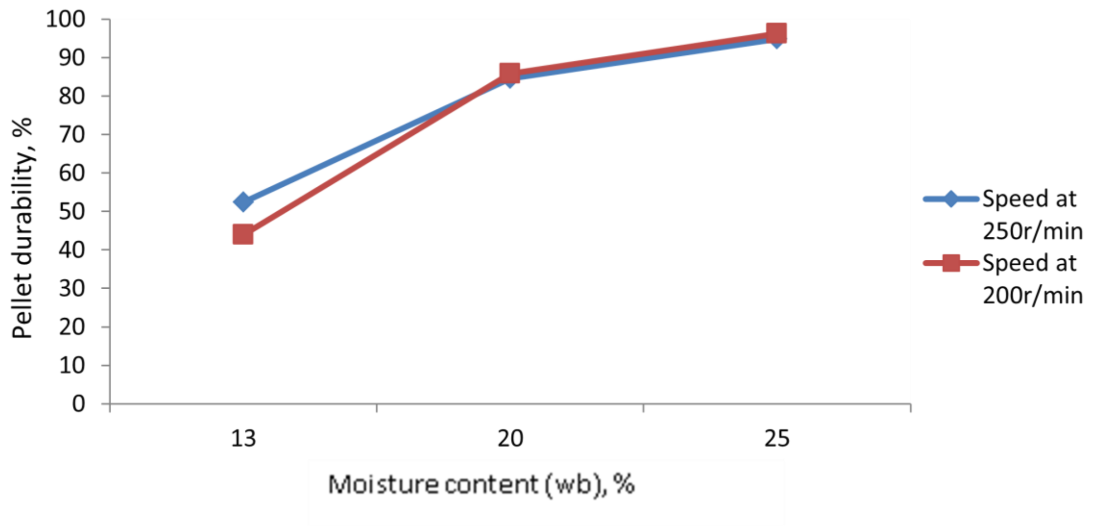


Figure 4b Pellet durability for 350 kg/hr feed rate

$$PD = -1.099 + 3.927 \times A - 4.974E - 003 \times B + 0.014 \times C \qquad (7)$$

R^2 =0.8806

Where, A represents moisture content, %; B is the feed rate, kg/hr; and C is the speed,

3.5 Pellet bulk density

The results is as presented in Table 6.

Table 6 Results for pellet bulk density

A , %	B , kg/hr	C, r/min	PBD, g/cm^3
13	500	250	0.3
13	350	250	0.24
13	500	200	0.28

13	350	200	0.29
20	500	250	0.38
20	350	250	0.56
20	500	200	0.53
20	350	200	0.53
25	500	250	0.64
25	350	250	0.90
25	500	200	0.94
25	350	200	0.96

Note: A= moisture content, B= feed rate, C= shaft speed, and PBD= pellet bulk density.

The pellet bulk density followed a similar pattern of increase from 13% to 25% moisture content with 13% m.c. having the lowest bulk density in g/cm^3 and 25% m.c has the highest pellet bulk density in g/cm^3 as observed in Table 6 above. Increase in moisture tends to increase the weight and in turn the bulk density. This is also in agreement with Fallahi et al. (2013) where increase in speed resulted in decrease in bulk density.

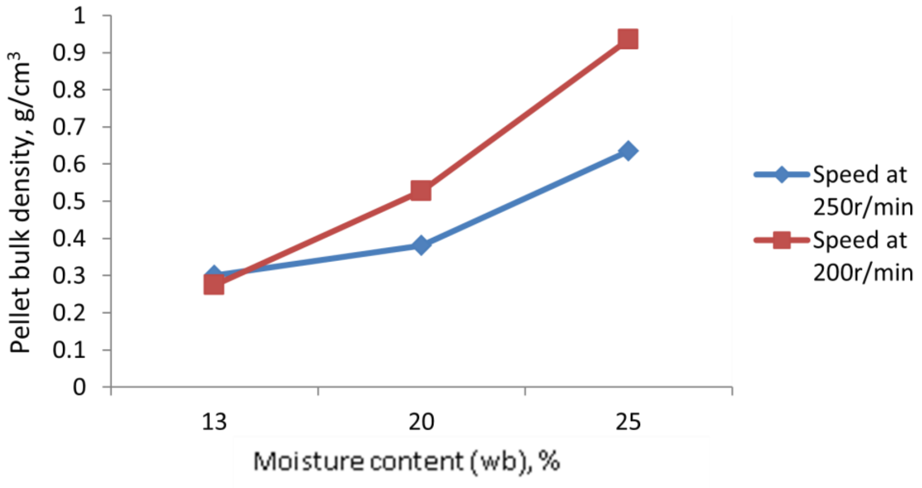


Figure 5a Pellet bulk density for 500 kg/hr feed rate

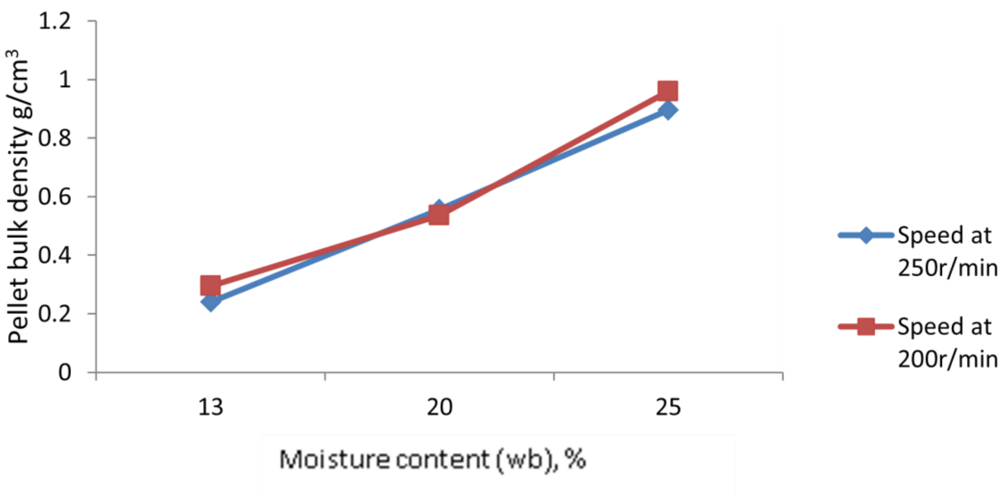


Figure 5b Pellet bulk density for 350 kg/hr feed rate

$$PBD = -0.255 + 0.053 \times A - 1.260E - 004 \times B - 6.667E - 004 \times C \quad (8)$$

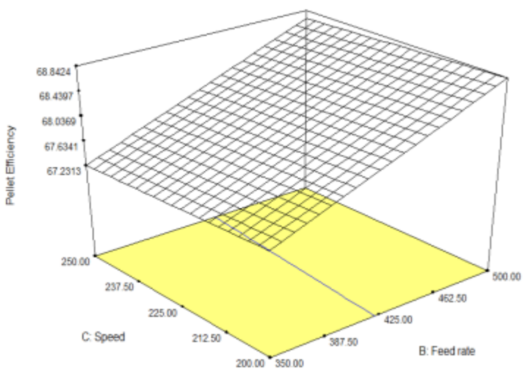
$R^2 = 0.8977$

Where, A represents moisture content, %; B is the feed rate, kg/hr; and C is the speed, r/min.

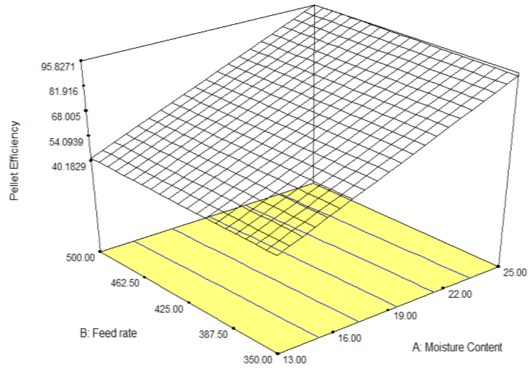
3.6 Optimisation

Optimum conditions depending on variables for evaluation of the pelleting press were determined to obtain maximum pellet efficiency, throughput capacity, pellet durability and pellet bulk density. First order polynomial models obtained in this study were utilised for each response in order to determine the specified optimum conditions. The moisture content, die speed and feed rate were selected in the range of 13%-25%, 200-250 r/min, 350-500 kg/hr respectively. Numerical Optimisation was done in Design Expert 6.0.6 with models developed by these independent variables. After optimisation, ten different solutions were obtained; the solution with the maximum desirability was selected. The optimum conditions for the evaluation of the pellet press are moisture content 25% feed rate 499.99 kg/hr, speed 250 r/min with the desirability of 0.986. At these conditions, pellet efficiency 95.7893%, throughput capacity 166.276 kg, pellet durability 98.0435% and pellet bulk density 0.846702 g/cm^3 is obtained.

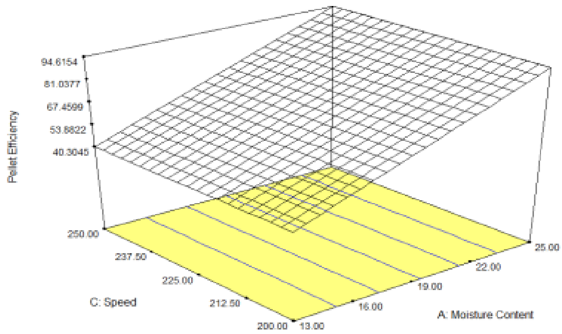
The response surface plots that indicate the interactions of the moisture content, feed rate and speed on pellet efficiency, throughput capacity, pellet durability and pellet bulk density are shown below Figures 6 to 9:



a.

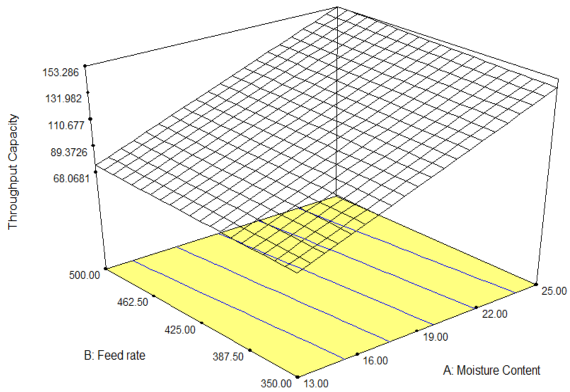


b.

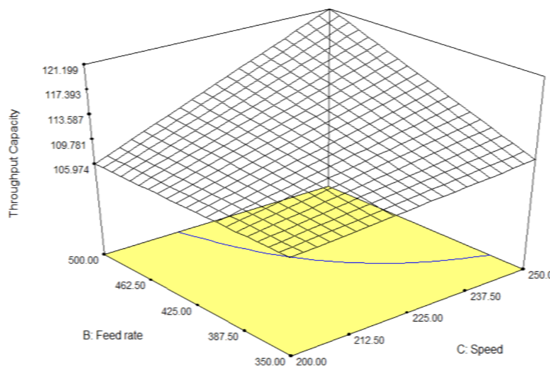


c.

Figure 6 Response surface plots for pellet efficiency (%) as a function of; a. feed rate(kg/hr) and moisture content (%). b. feed rate (kg/hr) and speed (r/min). c. speed (r/min) and moisture content (%)



a.



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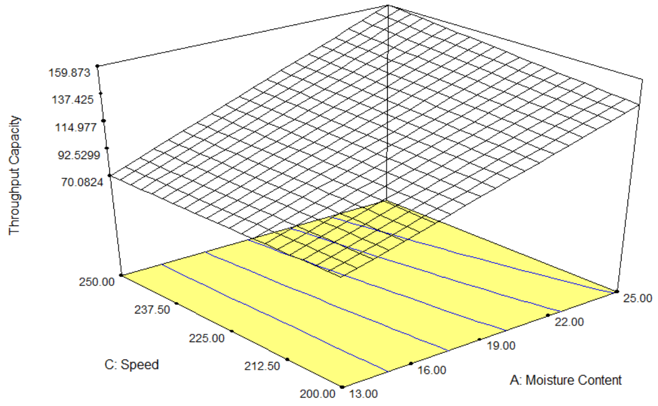
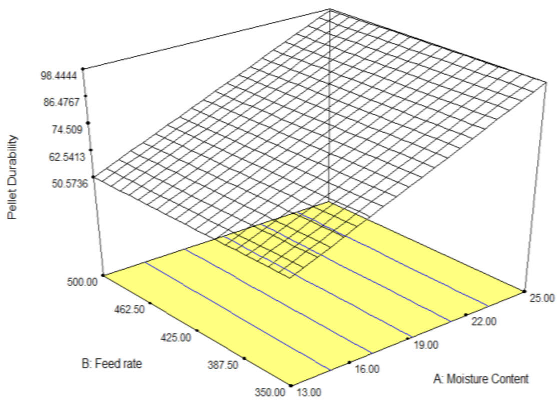
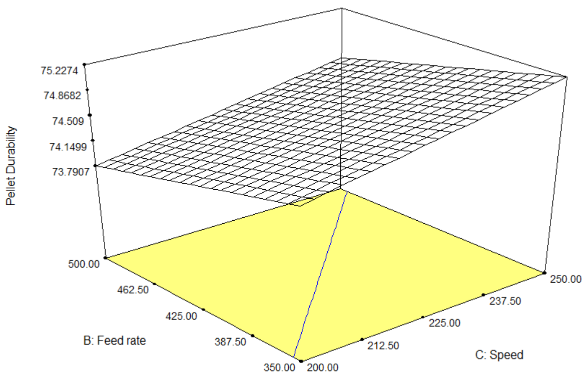


c.

Figure 7 Response surface plots for throughput capacity (kg/hr) as a function of; a. feed rate(kg/hr) and moisture content (%). b. feed rate (kg/hr) and speed (r/min). c. speed (r/min) and moisture content (%).



a.



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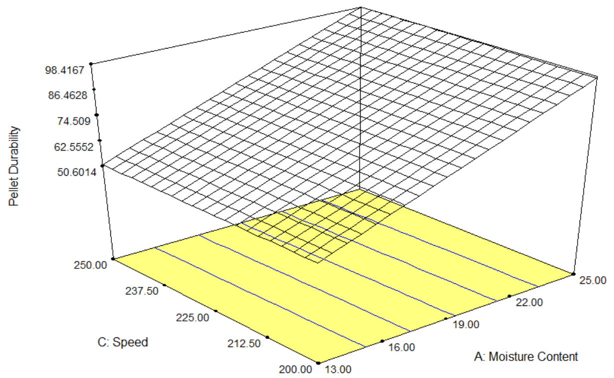
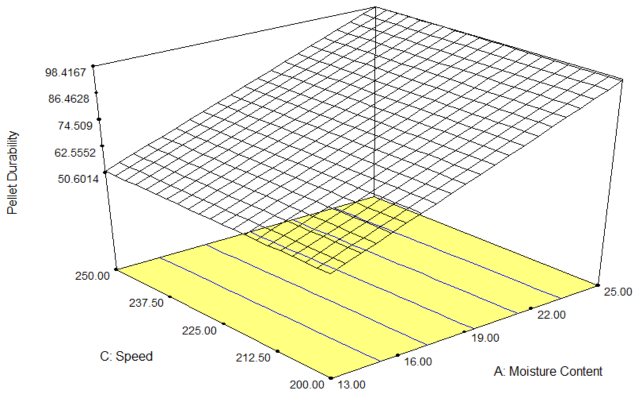
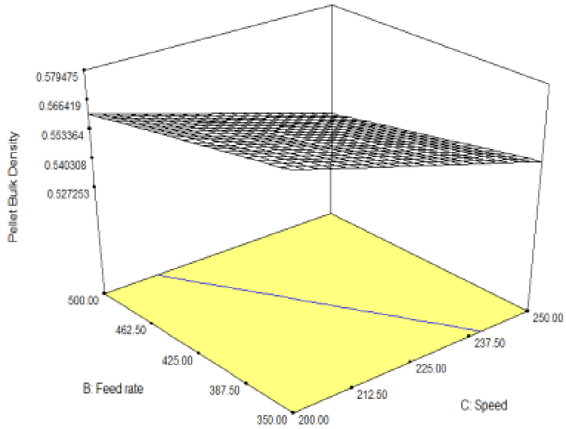


c.

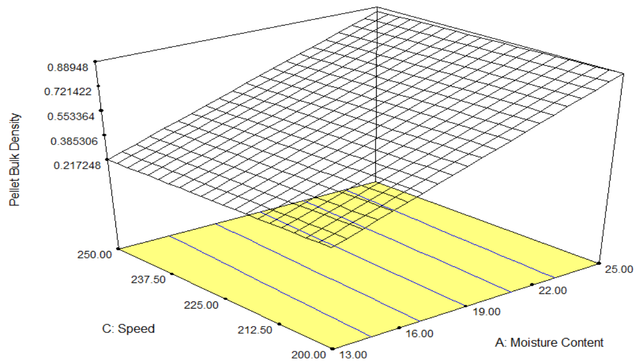
Figure 8 Response surface plots for pellet durability (%) as a function of; a. feed rate (kg/hr) and moisture content (%). b. feed rate (kg/hr) and speed (r/min). c. speed (r/min) and moisture content (%)



a.



b.



c.

Figure 9 Response surface plots for pellet bulk density (g/cm^3) as a function of; a. feed rate(kg/hr) and moisture content (%). b. feed rate (kg/hr) and speed (r/min). c. speed (r/min) and moisture content (%)

4 Conclusions and recommendations

Some performance evaluation parameters of the pelleting press were studied and the following conclusions were drawn:

(1) The effect of independent parameters was significant for pellet efficiency, throughput capacity, pellet durability and pellet bulk density with R^2 values of 0.9399, 0.9612, 0.8806 and 0.8977 respectively from the ANOVA analysis.

(2) Optimum conditions for maximum pellet efficiency, throughput capacity, pellet durability and bulk density corresponds to moisture content 25%, feed rate 499.99 kg/hr, speed 250 r/min with the desirability of 0.986. At this condition, pellet efficiency throughput capacity, pellet durability and pellet bulk density were recorded as 95.7893%, 166.276 kg, 98.0435%, 0.846702 g/cm^3, respectively.

This study provides useful information for engineers to improve the performance of the vertical shaft pelleting machines. The machine does not make use of steam thereby making it very easy to operate; however, a binder should be added to the feed to further strengthen the pelletized feeds otherwise the structural integrity of the pellets may be compromised easily as a result of low binding forces. The adoption of the pelleting machine by micro and small-scale fish farmers would go a long way in helping them to produce their own feed thereby alleviating the problems associated with the sourcing of imported feeds. However, only up to a maximum of 50% of the total moisture content of the material being processed is actually lost on leaving the machine. Heat is generated as a result of friction and shear and it is difficult to achieve adequate processing temperatures if the total moisture content of the material being fed is above 30%. High fat levels can also create problems. In practice to produce a shelf stable finished product, the initial moisture content of the material should be between 20%-26%.

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