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PERFORMANCE EVALUATION OF A FISH FEED PELLETIZING MACHINE

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ABSTRACT

A pelletizing machine for the production of fish feed was designed and fabricated. It consists of a hopper, barrel which houses the screw conveyor (auger), the cutting knife and the die orifice. Power supply to the machine is from 2 kW, 1420 rpm single phase electric motor. The performance evaluation of the machine was carried out. The main objective was to investigate the effects of moisture contents and the speed of operation on the performance of the machine. It was observed that the pelletizing efficiency, throughput capacity and the percentage recovery of the machine increased with increase in moisture content and the speed of the machine. The machine showed higher throughput capacity of 19.7 kg/h with maximum pelletizing efficiency of 87.6%. Moisture content constituted a greater portion of variability in efficiency than speed. A unit increase in moisture content resulted in an increase of about 20% in pelletizing efficiency whereas a corresponding unit increase in speed only increased the pelletizing efficiency by 3%. The machine does not make use of steam thereby making it easier to operate. The adoption of the pelletizing machine by small and medium scale farmers would go a long way in helping them to produce their own feed with local contents thereby alleviating the problems associated with the sourcing of imported feeds.

Keywords: fish feed, pelletizing machine, performance evaluation, speed, moisture content, efficiency.

INTRODUCTION

It is an established fact that protein from foods of animal origins is lacking in everyday diet of many Nigerians. This deficiency is responsible for a great deal of ill-health and many deaths in almost all the states of Nigeria. Even in the absence of ill health, protein deficiency leads to poor growth, muscular weakness and increase in susceptibility to many diseases (FDF, 1995). The support to meet the demand by various domestic animals and fish from natural water has so far failed to provide the populace with balanced diet needed.

It is imperative therefore to increase protein production by all possible means. First is by the intensification of the existing means of production. And second by the introduction and development of additional source of protein. Fish culture in artificial water is one of the best way to increase the availability of food rich in protein. However, to get the best result from fish culture systems the role played by fish feed should also be defined. Although aquaculture is fast developing in Nigeria, the yields obtained from the fish farms are still low. The low yield has been attributed to inadequate supply of balanced fish diets (Faturoti and Akinbote, 1986). At the moment only few organizations are engaged in fish feed manufacturing in the country and it is still not possible to meet the large potential demands for feeds. However, there is a large potential of feed ingredients from local plant and animal sources which are capable of supplying the nutritive requirement of fish.

Pellet presses for the production of fish feed was first introduced in the mid 1920s (McEllhiney, 1987). The production of and demand for pelleted feeds for fish has grown until now. Over 98 percent of all feeds are fed in pelleted form in Europe and North America (Schultz, 1990). Yet, the demand for and production of pelleted feeds for fish are practically non-existent in many African countries in spite of the known feeding and handling advantages of pelleted feeds (Anon, 1991).

A pelletizer consist 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 (Mercier, 1980). The feed is forced through a restricted opening the die at the discharge end of the screw. According to Harper (1987), the factors that most influence the nature of the pelletized product are:

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, the physical state of
c) The materials and their chemical composition, particularly the amount and type of starches, protein and fats contain therein.
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.

According to Forberg (1987), the pressure flow, Q_p can be visualized by imaging a non-rotating screw with material flowing backwards from the die plate end towards the feed end. The rate of flow is dependent on the die pressure, material viscosity and screw geometry. It is calculated by:

$Q_p = -bp/mL$ …(1)

Where

p = pressure at die
L = Length of screw required to generate pressure at die (also referred to as degree of fill),
m = Newtonian viscosity, and
b = screw constant. Where

$b = {}^{1}/_{12}\, \pi D h^3 [1 - ne/t] \sin^2\Phi$ …(2)

Reduction of moisture content causes the pressure in the barrel to go up (Michael, 1984). This usually does not result in a reduction of output because the viscosity of the material goes up, offsetting the rise in pressure. Smaller die holes give greater resistance to flow through the die plate (Wiedmann and Strecker, 1987). Greater resistance causes higher die pressure and reduction of throughput. Cooling on the barrel also improves the friction between the barrel wall and the materials (Slater, 1984).

The first important factor in the pelletizing operation is the stable, consistent introduction of feed stocks into the machine. Inconsistent flow rates of feeds will more often than not produce inconsistent flow of products that will result in poor shape (Huber, 1990). According to Slater (1984), the required degree of accuracy of the feeders does depend on the tolerance of the extrusion process. Raw materials can greatly influence the design of feeders. The volume of material that screws can convey and the power they can transfer in pumping and heat generation is a design optimization which is made to suit different products (Wiedmann and Strecker, 1989). The conveying volume of a screw is a function of the screw speed, diameter and distance between flights of the screw (Rosen and Miller, 1973).

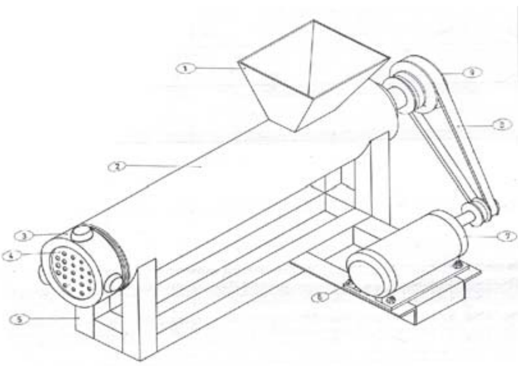
Huber (1988) observed that the screw speed directly affects the degree of bared fill and hence the residence time distribution and the share stress in the material being pelletized. The screw speed is a factor in determining the maximum volumetric output of the pelletizer.

MATERIALS AND METHODS

Description and operation of the machine

The component parts of the electrically operated fish feed pelletizer include the hopper, which was welded to a cylindrical base- the barrel. The barrel housed the screw conveyor (auger), the conveyor consist of two parts. The first part of the screw conveyor feeds in the material in granular form and the second part of the conveyor compressed the material into a semi-solid plasticized mass. The pelletized feed is forced out through the die. The diagram of the machine is shown in Figure-1 while plate1and 2 show the picture of the machine and pelletized feed, respectively.

The feed material is conveyed and pressed by a screw inside a tube or barrel leading to a rise in temperature due to increase pressure in the barrel. High temperature of operation in the presence of water promotes gelatinisation of starch component and stretching of expandable components. The expanded feed product is shaped by the openings in the die.



LEGEND

Part No.	Description	Qty	Part No.	Description	Qty
1	Hopper	1	8	Belt	1
2	Barrel	1	9	Pulley	1
3	Casing	1	10	Knife	1
4	Orifice	1	11	Shaft	1
5	Stand	1	12	Worm	1
6	Bolt	4	13	Bearing	1
7	Electric motor	1			

Figure-1. Isometric view of pelletizing machine.

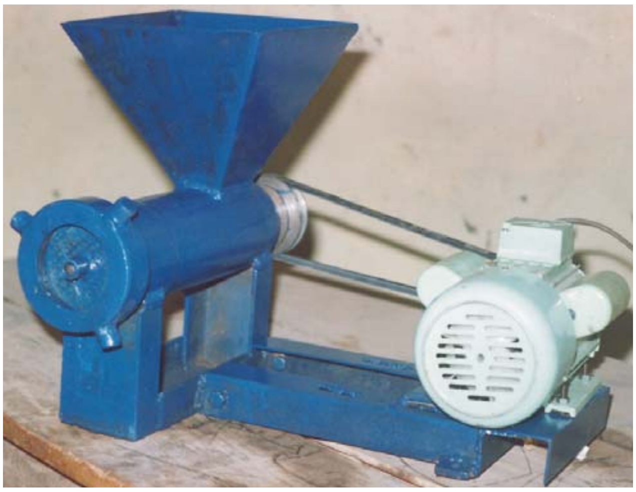


Plate-1. Picture of the pelletizing machine.

Plate-2. Fish feed pellets produced.

Performance tests of the Pelletizer

The feed used for the test was poultry feed (super starter chicks mash). However, it was milled again to give very fine aggregates. Three samples of the feed weighing 1 kg each was prepared at a moisture content of five percent and was tested at three machine speeds of 400rpm, 600rpm and 900rpm respectively. The speed of the machine was varied by changing the diameter of the pulley to give three different speed values for each replicate. These processes were repeated for additional five moisture contents of 7%, 9%, 11%, 13% and 15%, respectively, thereby making the samples tested to be eighteen.

The fish feed pelletizing machine was evaluated in terms of percentage of materials retained percentage unpelleted, pelleting efficiency, output capacity (kg/h) and throughput capacity (kg/h). The levels of the variables for testing the pelletizing machine are included in Table-1.

Table-1. Experimental plan for evaluation of fish feed Pelletizer.

#	Variables	Levels
1.	Feed moisture content (%)	5,7,9,11,13,15.
2.	Machine speed (rpm) (m/s)	400, 600, 900. (3.36m/s, 5.04m/s, 8.06m/s)

Determination of pelleting efficiency

The pelleting efficiency of the machine was calculated by the following procedures:

i) Total feed input

$$T_F = Q \times K \qquad \ldots(3)$$

Where:

T_F = Total feed input per unit weight
Q = Feed rate (kg/h)
K = Co-efficient of friction between barrel wall and feed material (Mohsenin, 1978)

ii) Pelleting efficiency (η_P)

$$\eta_P = \frac{W_A}{T_F} \times 100\% \qquad \ldots(4)$$

Where:

W_A = The quantity of actual feed pelleted obtained at the main die orifice per unit time (kg/h)

Determination of percentage recovery (P_R)

The fraction of the pelleted feed recovered at the die orifice.

$$\text{Percentage recovery}(P_R) = \frac{W_P}{W_O} \times 100\% \qquad \ldots(5)$$

Determination of throughput capacity (T_C)

$$T_C(kg/h) = \frac{W_O}{T}(kg/h) \qquad \ldots(6)$$

Where T is the time taken in hours.

Determination of percentage pelleted

$$Percentage\ \text{Pelleted}(\%P) = \frac{W_A}{W_O} \times 100\% \qquad \ldots(7)$$

Determination of percentage unpelleted

$$Percentage\ \ Unpelleted(\%U_P) = \frac{W_P - W_A}{W_O} \times 100\% \qquad \ldots(8)$$

Where:

W_A = Actual weight pelleted
W_0 = Original weight of feed

RESULTS AND DISCUSSIONS

Summary and Statistics of Machine Performance

Figure-2 shows that the efficiency of the machine increases with increase in the speed of the machine. Also at the highest moisture content the efficiency of the machine was 87.56%. The output capacity, throughput capacity, percentage recovery and percentage pelleted all experienced increase in magnitude as the speed of machine and moisture content increased (Figures 3 to 6). However the percentage retained of the machine and the percentage unpelleted increases as the speed of the machine and moisture content decrease (Figures 7 and 8). It could be deduced from the above result that moisture content and machine speed have significant effect on the performance of the machine.

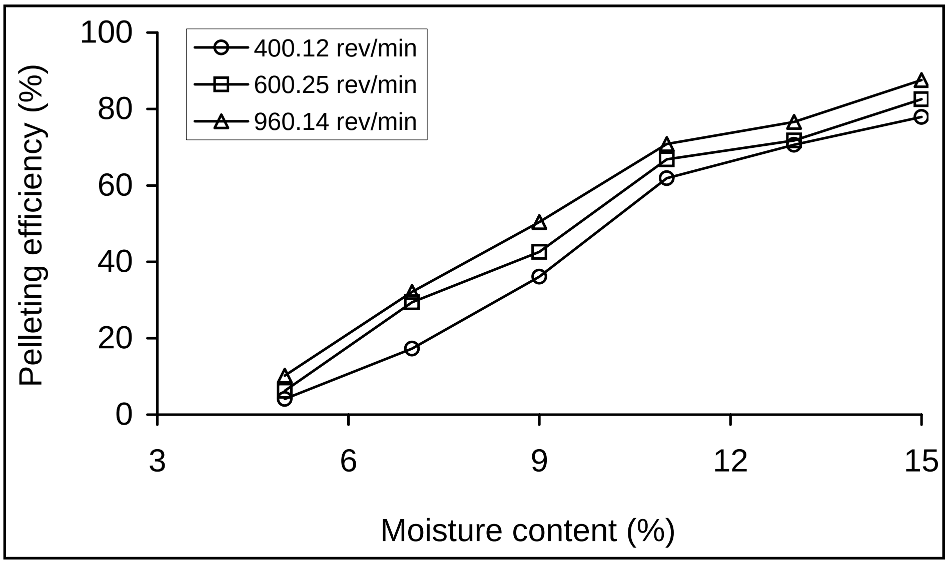


Figure-2. Effect of machine speed and moisture content on the pelletizing efficiency of the machine.

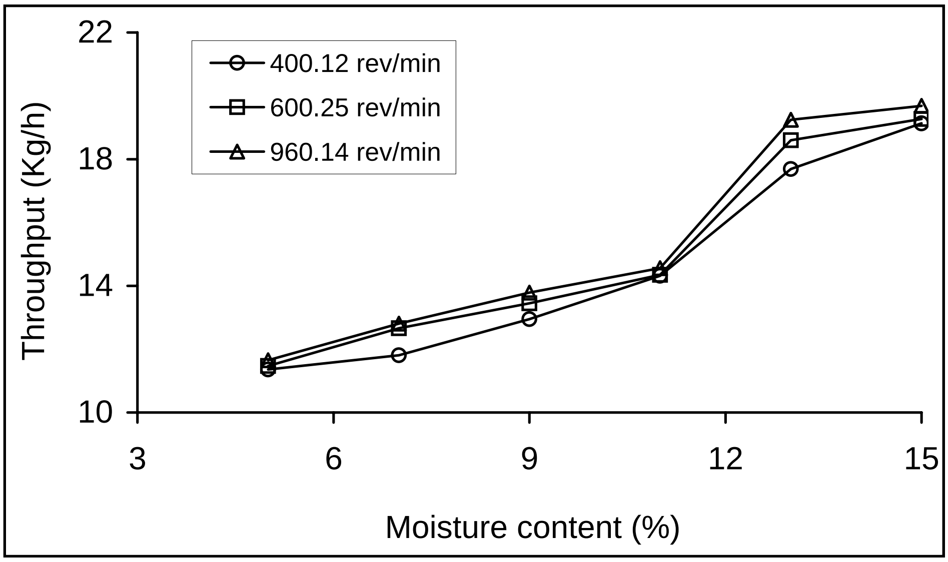


Figure-3. Effect of machine speed and moisture content on the throughput capacity of the machine.

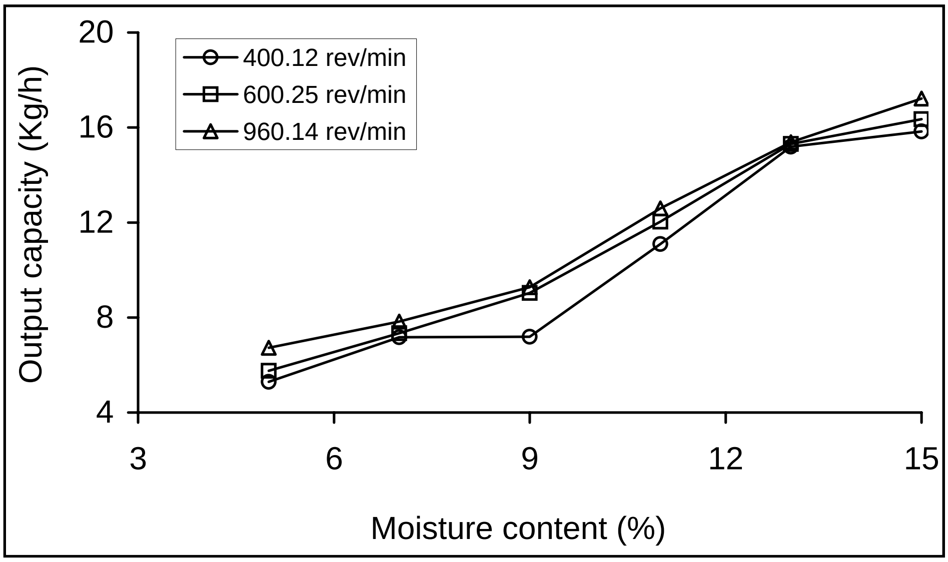


Figure-4. Effect of machine speed and moisture content on the output capacity of the machine.

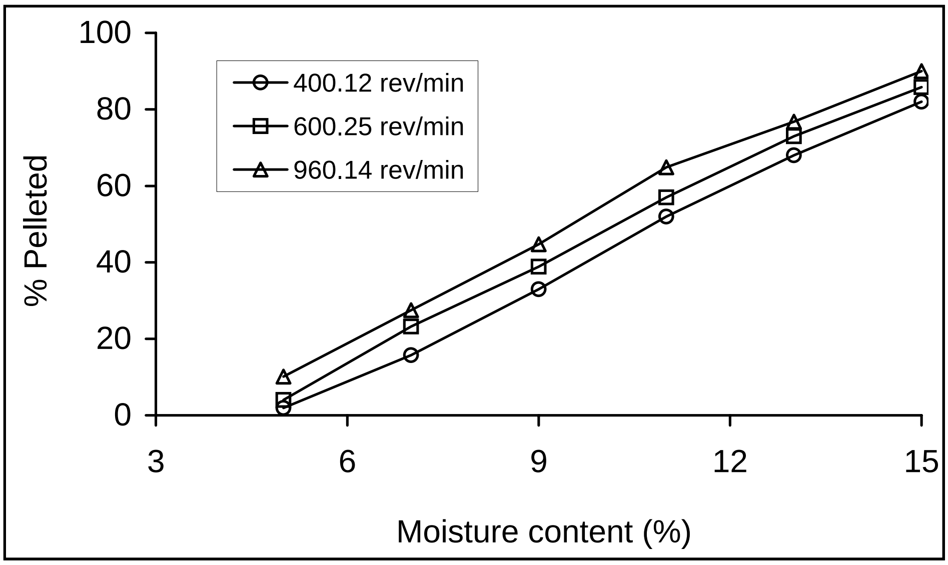


Figure-5. Effect of machine speed and moisture content on the percentage pelleted of the machine.

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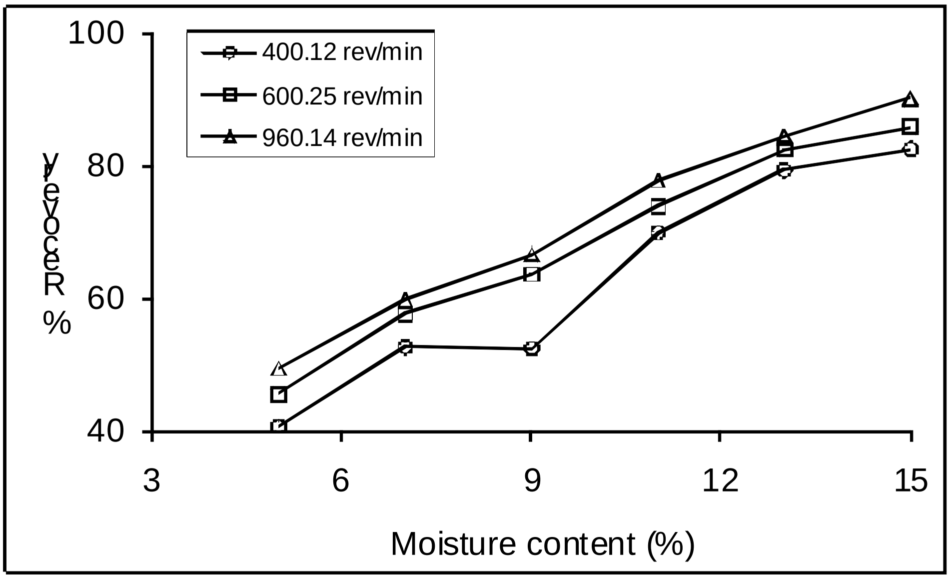

Figure-6. Effect of machine speed and moisture content on the percentage recovery of the machine.

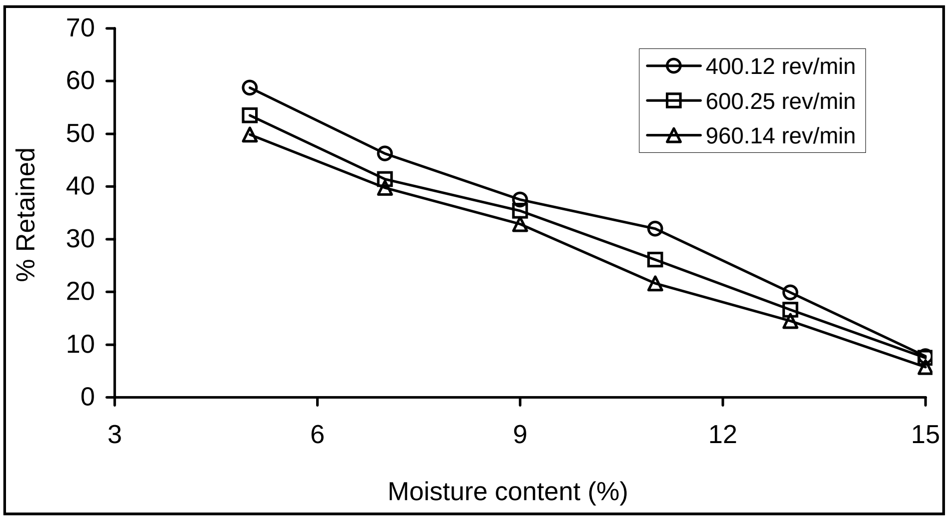

Figure-7. Effect of machine speed and moisture content on the percentage retained of the machine.

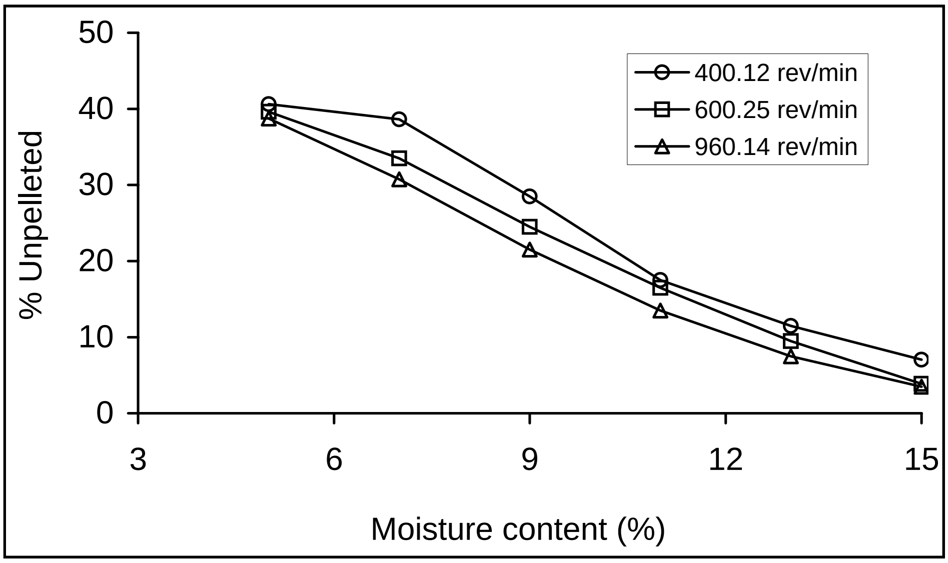

Figure-8. Effect of machine speed and moisture content on the percentage unpelleted of the machine.

Effect of moisture content on pelletizing performance

The Analysis of Variance (ANOVA) and Least Significance Test were used to investigate the effect of moisture content on the parameter of evaluation of the machine. The speed of the machine was kept constant while the moisture content varied. It was observed (Table-2) that the pelletizing efficiency, the output capacity, the throughput capacity, the percentage pelleted, percentage recovery, percentage unpelleted and the percentage retained were all significant at $p<0.01$.

The LSD test was carried out for the evaluation parameters of the machine at constant speed and the moisture content was varied. The result showed that the evaluation parameters of the machine are highly significant. Table-2 shows the effect of moisture content on the pelletizing efficiency.

The above result was in line with the observation of Linko *et al*. (1982), that there is always high temperature rise inside the barrel; the presence of water promotes gelatinisation of starch components and stretching of expandable components.

Effect of machine speed on pelletizing performance

Table-4 shows the ANOVA result when the moisture contents was kept constant and speed of operation was significant for the evaluation of pelletizing efficiency, percentage retained, percentage unpelleted, percentage recovery and percentage pelleted of the machine at $p<0.01$, whereas the speed of operation was not significant for throughput capacity and the output capacity at 38% and 11% respectively.

The result of LSD, Table-3 shows speed as a varied factor while the moisture content was treated as a constant. The pelletizing efficiency, percentage unpelleted and the percentage recovery all showed remarkable level of significance at $p<0.05$, while the output capacity showed level of significance at Machine speeds one and three only. The throughput capacity of the machine has no significant effect at the three machine speeds.

The above results corroborated the observation of Yaccu (1985) 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.

Modeling results

The regression statistics for the models explaining variation in the pelletizing efficiency, output capacity, throughput capacity, percentage recovery, percentage pelleted, percentage retained and percentage unpelleted is presented in Table-4. Moisture content contributed about 98% of variation in pelletizing efficiency with an overall standard error of 0.39 ($p=0.000$). The model coefficients were significant at 5% and 1% levels. Speed of operation explained an insignificant ($p>0.05$) value of variation of 15% in pelletizing efficiency. Moisture content contributed a greater portion of variability in efficiency than speed. A unit increase in moisture content (Φ) resulted in an increase of about 20% in pelletizing efficiency whereas a corresponding unit increase in speed only increased the efficiency by 3%.

This result is in agreement with the fact that moisture content is highly significant in the performance evaluation parameters of the machine since it is needed for the gelatinization of the feed, though speed is also important in the volumetric output of the machine.

Table-2. ANOVA result for evaluation parameters on effect of moisture content.

	Sum of Squares	df	Mean Square	F	Sig.
% RETAINED Between Groups	5070.372	5	1014.074	1616.181	.000
Within Groups	10.667	17	.627		
Total	5081.038	22			
%UNPELLETED Between Groups	3485.951	5	697.190	1111.147	.000
Within Groups	10.667	17	.627		
Total	3496.617	22			
% RECOVERY Between Groups	4487.930	5	897.586	1430.528	.000
Within Groups	10.667	17	.627		
Total	4498.597	22			
% PELLETED Between Groups	17541.330	5	3508.266	5591.299	.000
Within Groups	10.667	17	.627		
Total	17551.997	22			
THROUGHPUT Between Groups	196.370	5	39.274	62.593	.000
CAPACITY Within Groups	10.667	17	.627		
Total	207.037	22			
OUTPUT Between Groups	354.318	5	70.864	112.939	.000
CAPACITY Within Groups	10.667	17	.627		
Total	364.984	22			
PELLETIZING Between Groups	15817.758	5	3163.552	5041.910	.000
EFFICIENCY Within Groups	10.667	17	.627		
Total	15828.424	22			

Table-3. LSD Result for evaluation parameters.

Dependent Variable (1)FAC	(J) FAC	Mean Difference (I-J)	Std Eror	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PELLETIZING 1.00 EFFICIENCY	2.00	-23.2000*	.5601	.000	-24.3817	-22.0183
	3.00	-36.4000*	.5601	.000	-37.5817	-35.2183
	4.00	-60.7000*	.5601	.000	-61.8817	-59.5183
	5.00	-65.6000*	.5601	.000	-66.7817	-64.4183
	6.00	-76.6333*	.6050	.000	-77.9098	-75.3569
2.00	1.00	23.2000*	.5601	.000	22.0183	24.3817
	3.00	-13.2000*	.5601	.000	-14.3817	-12.0183
	4.00	-37.5000*	.5601	.000	-38.6817	-36.3183
	5.00	-42.4000*	.5601	.000	-43.5817	-41.2183
	6.00	-53.4333*	.6050	.000	-54.7098	-52.1569
3.00	1.00	36.4000*	.5601	.000	35.2183	37.5817
	2.00	13.2000*	.5601	.000	12.0183	14.3817
	4.00	-24.3000*	.5601	.000	-25.4817	-23.1183
	5.00	-29.2000*	.5601	.000	-30.3817	-28.0183
	6.00	-40.2333*	.6050	.000	-41.5098	-38.9569
4.00	1.00	60.7000*	.5601	.000	59.5183	61.8817
	2.00	37.5000*	.5601	.000	36.3183	38.6817
	3.00	24.3000*	.5601	.000	23.1183	25.4817
	5.00	-4.9000*	.5601	.000	-6.0817	-3.7183
	6.00	-15.9333*	.6050	.000	-17.2098	-14.6569
5.00	1.00	65.6000*	.5601	.000	64.4183	66.7817
	2.00	42.4000*	.5601	.000	41.2183	43.5817
	3.00	29.2000*	.5601	.000	28.0183	30.3817
	4.00	4.9000*	.5601	.000	3.7183	6.0817
	6.00	-11.0333*	.6050	.000	-12.3098	-9.7569
6.00	1.00	76.6333*	.6050	.000	75.3569	77.9098
	2.00	53.4333*	.6050	.000	52.1569	54.7098
	3.00	40.2333*	.6050	.000	38.9569	41.5098
	4.00	15.9333*	.6050	.000	14.6569	17.2098
	5.00	11.0333*	.6050	.000	9.7569	12.3098

The mean difference is significant at the 5% level

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Table-4. ANOVA result for evaluation parameters and the effect of machine speed.

	Sum of Squares	df	Mean Square	F	Sig.
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Within Groups	10.667	9	.627		
Total	17551.997	11			
THROUGHPUT Between Groups	196.370	2	39.274	62.593	.383
CAPACITY Within Groups	10.667	9	.627		
Total	207.037	11			
OUTPUT Between Groups	354.318	2	70.864	112.939	.011
CAPACITY Within Groups	10.667	9	.627		
Total	364.984	11			
PELLETIZING Between Groups	15817.758	2	3163.552	5041.910	.000
EFFICIENCY Within Groups	10.667	9	.627		
Total	15828.424	11			

CONCLUSIONS AND RECOMMENDATIONS

The pelletizing machine for the production of fish feed was designed, fabricated and evaluated. The machine showed higher throughput capacity of 19.7 kg/h with maximum pelletizing efficiency of 87.60% and favourable economic advantage over bigger ones being imported into the country. The regression models developed in the study could be used to estimate machine functional performance using moisture content and machine speeds. Thus the pelletizing efficiency could be determined from:

$$\eta = 7.75\Phi + 0.017v - 33.60 \quad \ldots(14)$$

with R^2 = 0.94, standard error of - 6.88 and $p<0.0001$ where Φ is the moisture content and v is the machine speed. Maximum efficiency was observed when the moisture content was high and the machine running at the highest speed. A unit increase in the moisture content (Φ) resulted in an increase of about 20% in pelletizing efficiency whereas a corresponding unit increase in speed (v) only increased the efficiency by 3%. This study provides useful information for engineers to improve the performance of pelletizing machines.

The machine does not make use of steam thereby making it very easy to operate; however, binder could be added to the feed to further strengthen the pelletized feeds. The adoption of the pelletizing machine by small scale and medium 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.

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