Extruder performance in pelleting conventional forage fed to grasscutters (Thryonomys swinderianus) in captivity in Ghana

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Abstract— **A Pelletizing machine for the production of pelleted feed for grasscutters in captivity was designed and fabricated. It consists of a hopper, a barrel that houses a screw conveyor and pipes of 18.0mm diameter. Power was provided to the extruder by a 2.2kW, 1430 rpm and 3 - phase electric motor. The drive and driven pulleys were 213.mm and 135mm in diameter respectively. The study was to find out the effect of moisture, particle size and feed components on the performance of the pelletizer. It was observed that moisture content, particle size and feed component had effect on the performance of the extruder. The initial feed weight, total feed input, percent pelleted, throughput capacity and pellet efficiency were highly significant P<0.001, while input time and pelleting time were significant P<0.05, (SAS, 2008). The highest pelleting efficiency as 75.08% was obtained by the feed with its components that passed once through the 2.0mm screen size of the hammer mill at a moisture level of 62.50%. Machine throughput capacity was 42.67kg/m3 and 96.88% pelleted feed. The two pass component of the feed had its maximum pelleting efficiency of 75.10%, moisture content of 56.25% and the machine throughput capacity as 54.67kg/m3 and 97.34% of the feed pelleted. It is therefore recommended that the main feed components be ground into fine particles to achieve higher throughput capacity and pelleting efficiencies. The absence of pre-conditioning with either steam or hot water and the none usage of commercial binders will make it easier to use the machine by small and medium scale grasscutter farmers to produce pelleted feed in their homes to remove the drudgery of transporting, handling and storing large quantities of the forage that need larger storage structures.**

Nomenclature

INPUT input time
PTIME pelleting time
PECPEL percent pelleted
PLWT pellet weight
PAS number of passes in hammer mill
PDIFF probability difference procedure
TOF total feed input
TRUPUT throughput capacity
SAS statistical analysis system

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1. INTRODUCTION

Conservationist and advocates of wild animal domestication have argued for the farming of favourite species to increase bush meat production and supply in the West African sub-region to reduce the pressure on wild population Achana, 2002. The wild animal species they advocated for included the grasscutter, (*Thryonomys swinderianus*), giant rat, (*Cricetomys gambianus*) and the African giant snail (*Achatina achatina*), (National Research Council NRC), 1991.

The grasscutter that is susceptible to few diseases or health problems and can be maintained on a wide variety of food has been advocated for domestication because of the quality of its meat. It is considered a delicacy by both the rich and the poor alike and the most popular and perhaps the most expensive meat in Ghana. Grasscutter in captivity has been advocated as one of the best means to increase the availability of food rich in protein for both the rural and urban people of Ghana. However, to get the best result from grasscutter rearing systems, the role played by their feed should be defined. Although grasscutter farming has gained grounds in Ghana, their growth performance is very low, due to inadequate supply of balanced diets.

Forage and crop residue which are inexpensive and available feedstuff for feeding the grasscutter in captivity are nutritionally poor and not balanced for optimum performance and growth of the grasscutter therefore requires supplementation. In order to make these forage material available for the grasscutter throughout the year, the challenges associated with them must be resolved. Forage materials have high moisture content, irregular shape and size, low bulk density, difficult to handle, transport, store and utilize in its original form. The solution to these problems is densification of the forage into pellet to increase its bulk density from a lower level of 20 to 40 kg/m^3 to as high as 400 to 800 kg/m^3 (Maniet *et al*., 2003; Obernberger *et al*., 2004; MacMullen *et al*., 2005). This will reduce the cost of transportation, handling and storage.

Though, over 98% of all animal feeds in North America and in Europe are fed in pelleted form, (Schultz, 1990), the need for and production of pelleted feed for grasscutters in captivity in Ghana are practically non-existent, in spite of the known advantages pelleted feed has over the bulky raw material or ground feed.

Incorporating Elephant grass,(*Pennesetum, purpurenum*), gliricidia leaves and cassava with the peel as the main roughage sources in a complete dietary ration of grasscutters and their further pelleting would be one of the ways for their economic utilization.

An extruder consists of a screw in which feed is compressed and worked to form a semi-solid mass. The feed is then forced through the restricted opening of pipes at the discharge end of the screw. The rate of flow is dependent on the pipes pressure, material viscosity and screw geometry.(Fasina *et al.* 2006).

The objective of the study was to evaluate the performance of the designed and fabricated pelletizer to produce pelleted feed from grass to feed grasscutters in captivity.

2. Materials and Methods

Feed component

Four week elephant grass (*Pennisetum purpureum*.) and Gliricidia leaves were harvested from the college cocoa plantation field while the cassava was purchased from a farmer. The selection of the material was based on the fact that they are the most used feed of the grasscutter and are common and available all year round. The elephant grass and cassava tubers were chopped into pieces of sizes between 2-4 cm whiles the gliricidia leaves were left whole. They were separately shade dried at a temperature of 25^{o}C and ground in a hammer mill of sieve size 2.0mm. The ground materials were mixed according to a feed formulated formula together with some industrial ingredients to obtain a crude protein level of 18% as stated by (Kusi, 2012).

Composition of pelleted feed rations

Table 1 gives a descriptive summary of the various levels of inclusion of feedstuffs in the two rations.

Table 1 composition of feed ration

Ration with Urea				Ration with soya bean meal			
Ingredients	Inclusive level (%)	Crude protein (%)	Calculated crude protein (%)	Ingredients	Inclusive level (%)	Crude protein (%)	Calculated crude protein (%)
Major Ingredient				**Major Ingredient**			
Elephant grass	45.0	7.40	2.96	Elephant grass	40.00	7.40	2.96
Gliricidia leaves	29.0	19.70	5.52	Gliricidia leaves	28.00	19.7	5.52
Cassava with peel	22.0	4.4	0.96	Cassava with peel	10.00	4.4	0.44
Urea	2.8	44	8.05	Soya bean meal	21.00	44	9.24
Minor Ingredients				**Minor Ingredients**			
Dicalcium phosphate	0.28			Dicalcium phosphate	0.25		
Premix	0.35			Premix	0.25		
Common salt/table salt	0.44			Common salt/table salt	0.5		
Sodium sulphate	0.13						
Total	100.00		17.49	Total	100.00		18.16

The calculated crude proteins for the two rations are 17.50% and 18.16% respectively. Our calculation was based on Kusi (2012) who postulated that the crude protein required for optimal growth of grasscutters from weaning to puberty stage is 18%.

Pelletizer Operation

The three Phase electrically operated extruder consists of an auger enclosed in a cylindrical barrel. The semi solid mass is pushed through the evenly spaced 18.0mm pipes.

Fig 1. Pelletizer

The heat produced during the operation of the pelletizer further helped in the gelatinization of the starch, cellulose and hemi-cellulose and denaturing of the protein in the presence of the moisture also improved the machine's performance, as reported by Adapa, (2004).

Performance Test

The feed used had a combination of Elephant grass, gliricidia leaves and cassava with the peel and either soy meal or urea as the feed component with other commercial additives to give a crude protein of 18.0%. One kilogram (1.0kg) each of the formulated feed was prepared at four moisture levels and replicated four times. In all there were 32 treatments for each feed ration. Friction between the feed particles and the wall of the pipes resisted the free flow of the feed resulting to the compressing of the particles against each other in the pipes to form pellets.

The pelletizer was evaluated in terms of the effect of moisture content, particle size and feed component on the performance of the pelletizer: pelleting time, total feed input, pellet weight, percent pelleted, machine throughput capacity and machine pelleting efficiency based on the procedure of Ojomo *et al.*, 2010 in their evaluation of a fish feed pelletizing machine.

Determination of pelleting efficiency
The pelleting efficiency was determined using the formula below

Pelleting efficiency $\eta_p = \frac{W_A}{T_F} \times 100\%$ ....(1)

Where W_A is quantity of actual feed obtained at the main orifice per unit time (kg/h)

$T_F = Q \times K$ ....(2)

T_F *is total quantity of feed input* per unit weight
Q = Feed rate (kg/h)
K = Co-efficient of friction between barrel wall and feed material (Mohsenin, 1978)
K = 0.26, for straw on mild steel surface

Determination of percentage pelleted (Pr)
The stated formula was used to calculate the percentage recovery of the pellet

Percentage recovery $P_r = \frac{W_p}{W_o} \times 100\%$ ....(3)

Where W_p is weight of pelleted feed
W_o is original weight loosed of feed

Determination of percentage throughput capacity(Tc)
The percentage throughput capacity was determined using equation 4

Throughput Capacity $T_C = \frac{W_O}{T}(kg/h)$ ....(4)

T is time in hours

Determination of percentage unpelleted
This was determined using the following formula;

Percentage unpelleted $(\%U_p) = \frac{W_o - W_A}{W_o} \times 100\%$ ..(5)

3. Statistical Analysis

Data on extruder performance, i.e., initial weight of feed, Pelleting time, pellet weight, Total feed input, pellet efficiency, percent pelleted and the extruder throughput capacity were subjected to the Least Square Mean Analysis using the Generalized Linear Models (GLM) Type III Procedure, SAS, (SAS,2008).
In all of the analysis, differences between means were separated by the probability difference (PDIFF) procedure of SAS. (SAS, 2008). The importance of the independent factors in influencing the dependent factors was determined by using the coefficient of determination (R^2) through regression analysis (SAS,2008).
A study on the prediction of the extruder performance was carried out by regression analysis (SAS, 2008). Both properties were regressed individually on the moisture content, type of feed and particle size. The general simple linear regression equation was:
$Yi = \alpha + \beta X_i$
Where; Yi is the extruder performance of dependent variable, α is the intercept or the value of Yi when $X_1 = 0$, β is the coefficient of regression or slope defined as the change in Yi resulting from a unit change in Xi, Xi is the independent variable represented as;, MOIT, INFWT, INPUTT, PTIME, PEWT, PEEF, PECPEL and TRUPUT .

4. Results and Discussion

Effect of Moisture content and Particle size on production performance
Figures 1a and 1b indicate how the various moisture levels, type of feed and particle sizes affected the input time and pelleting time for ration 1 (urea inclusions). In figure 1a it was observed that the pelleting time was slightly higher than the input time and constant for all moisture levels except at 64.95% moisture level which took longer to input and pellet. Although the input time and pelleting time at moisture level 64.95% were equal the machine has to do extra work to have the raw feed mixed pelleted. On the other hand the two pass component mixed raw feedstuff, the input times are significantly higher than the pelleting times for the first and third moisture levels but equal to the pelleting times at the second and fourth moisture levels as indicated in Fig.1b. To achieve a lower pelleting times, the moisture levels of the feed must be lower. The machine pellets faster at feed moisture levels 53.25% and 53.76% for the ration 1, 2pass.

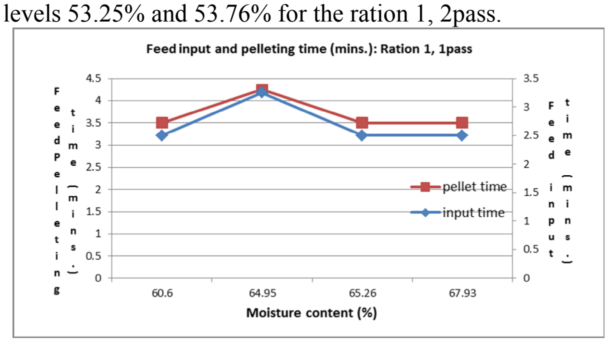

Fig 1a Feed input and pelleting time for Ration 1, 1Pass

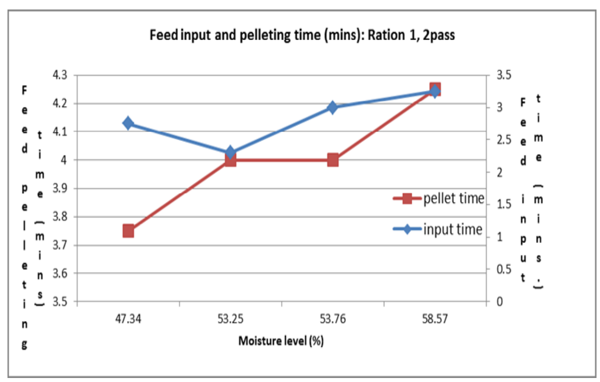

Fig 1b Feed input and pelleting time for Ration1, 2 Pass

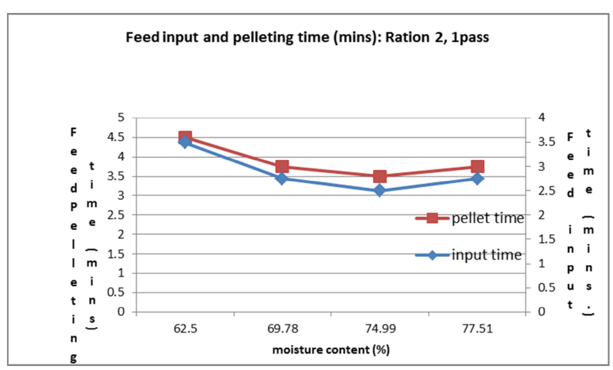

Fig 2a Feed input and pelleting time for Ration 2, 1pass

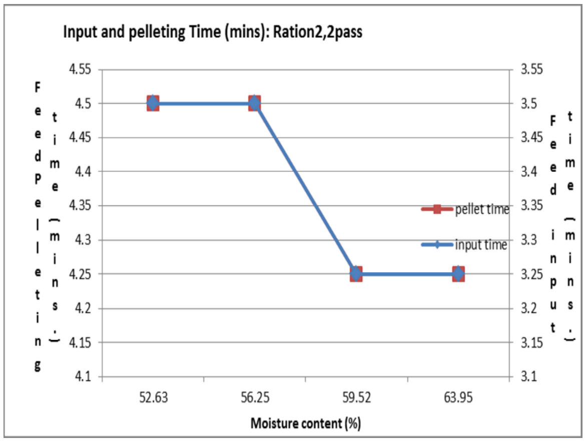

Fig 2b Feed input and pelleting time for ration2, 2 pass

The pelleting time for ration 2 (soy meal inclusive) were slightly higher than the input time for the 1pass component at all moisture levels and decreased almost linearly as the moisture levels increases until 74.99% moisture level when it suddenly increased again. The least input and pelleting times were observed at moisture level 74.99%. However, the 2 pass feed components of ration 2 had both their input and pelleting times been the same and vary linearly along the increasing moisture levels. The first two moisture levels are significantly higher than the last two which are also the same. In general it was observed that moisture levels 52.63% and 56.25% require more time to input and pellet as compared to moisture levels 59.52% and 63.95%

Percentage Pelleted and Machine Pelleting Efficiency

Figures 3a and 3b represents the graphical presentation of the effect of moisture content, type of feed and particle size on the Extruder pelleting efficiency (Ep), and percentage pelleted of ration 1. For ration 1, 1pass it was observed that the percentage pelleted and machine efficiency varies inversely along increasing moisture levels. An extension of the graph predicts convergence of the two eventually as indicated in Fig. 3a. For optimum performance (Machine Pellet efficiency = Percentage Pelleted) the moisture level of feed should be between a lower (60.60% and 64.95%) and the next higher (64.95% and 65.26%) moisture levels. With the 2 pass components of ration 1 both machine efficiencies and percentage pelleted rises and falls with moisture levels consecutively (Fig.3b). The optimum performance of the machine where pellet efficiency equals to percentage pelleted could be found between moisture levels of 53.50 to 53.76% for the 2 passes components of ration 1.

Figure 4a illustrates percentage pelleted rises along increasing moisture levels while pelleting efficiency decreases from the lower moisture level till at moisture level 74.99% where it rises again with the feed mix of ration 2, 1pass components. The optimum performance of the machine could be found in between moisture levels 69.78% and 74.99%. However the pelleting efficiency and percentage pelleted of ration 2, 2pass shows a steady distant relationship apart until they merged close to moisture levels 59.52 and diverged afterwards. To achieve the optimum performance of the machine the moisture content of the feed mix must be closer to 59.52 % (Fig 4b).

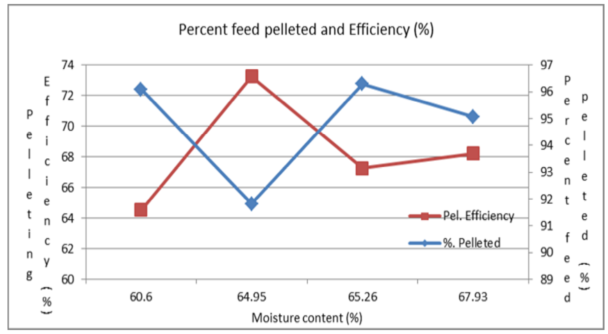

Fig. 3a. Machine pelleting efficiency and percent pelleted; ration 1, 1pass

From the figure, percent pelleted, and pelleting efficiency of the machine increased gradually until they got the optimal moisture content (64.94 %), as observed by, (Adapa et al., 2011).

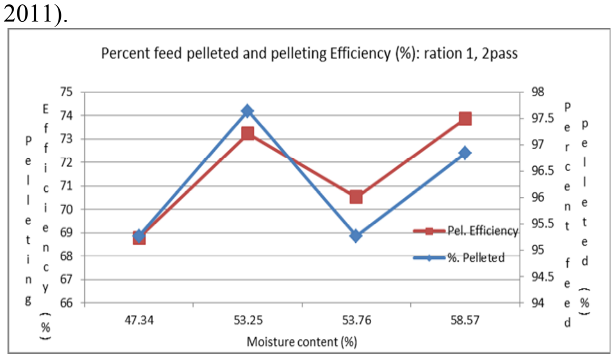

Fig. 3b. Machine pelleting efficiency and percent pelleted; ration 1, 2 pass

Figures 4a and 4b are the graphical presentation of the effect of moisture content, particle size and type of feed on pelleting efficiency and percentage pelleted of ration 2, (soybean inclusive).

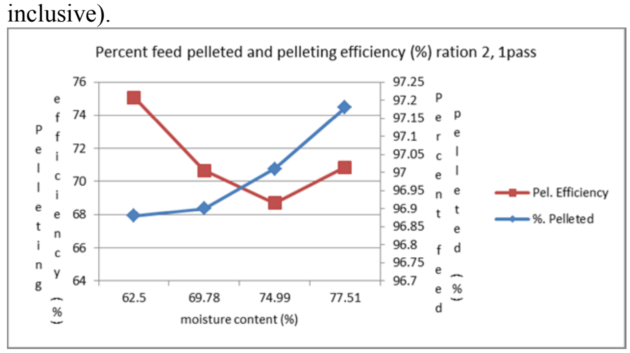

Fig.4a. Machine pelleting efficiency and percent pelleted; ration 2, 1 pass

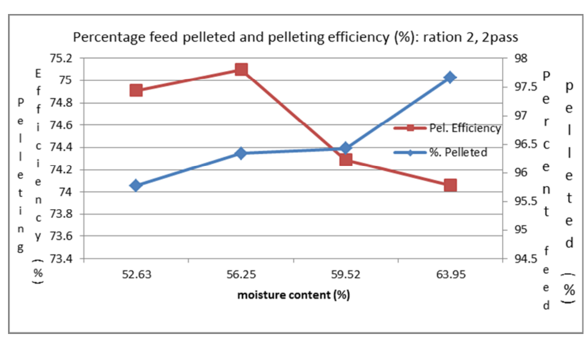

Fig.4b. Machine pelleting efficiency and percent pelleted; ration 2, 2 pass

Machine Through-put Capacity (tc), kg/hr.

Figures 5a and 5b indicates the throughput capacity of the pelletizer for the two feed rations of the one pass and two passes of the feed component through the hammer mill of 2.0mm screen.

The two graphs clearly shows that the pelletizer's throughput capacity increased with increased moisture content with the exception of ration one that had its main component ground twice in the hammer mill. The machine through put decreased at the second levels of moisture content (63.5 and 54.7 kg/hr) at 53.25% and 64.95% moisture contents respectively. Higher values of the machine through put were recorded by the pellets produced from the components that passed twice through the 2.00 mm hammer mill sieve.

The throughput capacity for ration 1, one pass ranged from 57.09 to 69.43 while those of the two pass ranged from 67.68 to 69.75kg/hr. The through-put capacity for the ration 2 was 42.67 to 56.80kg/hr and 50.53 to 60.71kg/hr for the one pass and two pass respectively. From the two graphs it is realised that the pelletizer had higher through-put capacity with ration 1 for both the one and two passes of the main feed components, because lesser time was spent during pelleting in the machine. This confirms observation made by Adapa (2011) that if the delay time in pelleting is high the machine throughput would be low.

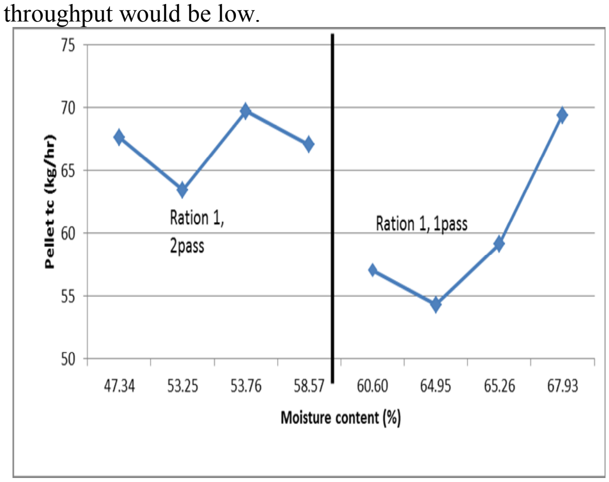

Fig 5a Graph of pelletize throughput capacity, ration 1 (1 and 2 pass)

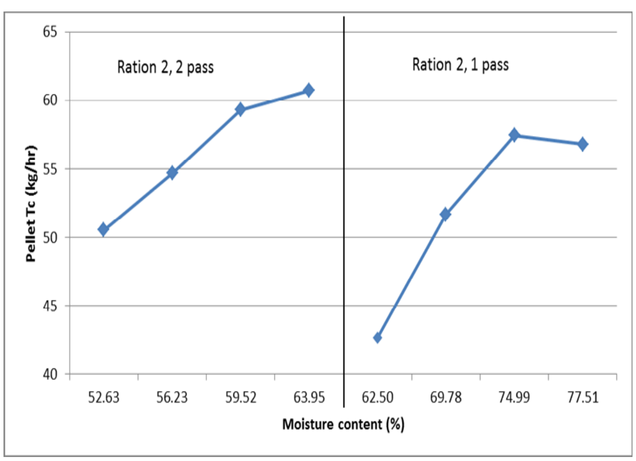

Fig 5b Graph of pelletize throughput capacity, ration 2 (1 and 2 pass)

5. MODELING RESULTS

The multiple regression statistic for the models explaining variation in initial weight of feed, input time, pelleting time, pelleted weight, total feed input, pelleting efficiency, percentage pelleted and throughput capacity is presented in tables 2 to 5.

Least square means and standard errors on extruder performance

TABLE 2: Least square means and standard error of the effect of particle size on extruder performance (LSD±SEM)

PARAMETER	TREATMENTS		P
	1 ONE-PASS	2 TWO-PASS	
Initial Weight	3.19±0.04	4.56±0.04	*<0.0001*
Input Time	2.70±0.15	3.06±0.14	*0.1577*
Pelleting Time	3.70±0.15	4.06±0.14	*0.1577*
Pellet Weight	3.01±0.05	4.44±0.04	*<0.001*
Total Feed Input	77.19±4.53	93.50±4.34	*0.0492*
Pelleting Efficiency	68.12±1.10	72.96±1.06	*0.0132*
% Pelleted	94.54±0.56	97.70±0.54	*0.0017*
Throughput Capacity	54.68±2.43	69.03±2.33	*0.0011*

TABLE 3. Least square means and standard error of the effect of type of feed on extruder performance

PARAMETER	TREATMENTS		*P*
	UREA	SOYA	
Initial feed weight	4.18 ± 0.03	3.56 ± 0.03	*< 0.0001*
Input Time	2.71±0.11	3.04±0.12	*0.0664*
Pelleting Time	3.71±0.11	4.04±0.12	*0.0664*
Pellet Weight	4.01±0.04	3.44±0.04	*< 0.0001*
Total Feed Input	96.57±3.46	74.85±3.53	*0.0002*
Pelleting Efficiency	69.18±0.84	71.91±0.86	*0.0455*
% Pelleted	95.72±0.43	96.53±0.44	*0.2332*
Through Put Capacity	68.95±1.85	54.76±1.89	*< 0.0001*

(LSD±SEM)

Apart from the percent pelleted the type of feed had influence on the initial feed weight, input time, pelleting time, pellet weight, total feed input, pelleting efficiency and the machine throughput capacity.

TABLE 4: Least square means and standard error of the effect of moisture content on extruder performance (LSD±SEM)

PARAMETER	TREATMENTS Moisture content (%)						*P*
	45-50 (%)	51-55(%)	56-60(%)	61-65(%)	66-70(%)	71+(%)	
Initial feed weight	3.23±0.07[a]	3.53±0.06[b]	3.74±0.04[c]	3.99±0.05[d]	4.29±0.05[e]	4.44±0.07[f]	*< 0.0001*
Input Time	2.36±0.27[a]	3.07±0.23[bc]	3.03±0.15[c]	3.09±0.17[abde]	3.07±0.20[abcde]	2.64±0.27[abcde]	*0.0335*
Pelleting Time	3.36±0.27[a]	4.07±0.23[bc]	4.03±0.15[c]	4.09±0.17[abde]	4.07±0.20[abcde]	3.64±0.27[abcde]	*0.0335*
Pellet Weight	3.08±0.08[a]	3.31±0.07[b]	3.55±0.05[c]	3.86±0.05[d]	4.120±0.06[e]	4.35±0.08[e]	*< 0.0001*
Pelleting Efficiency	65.87±1.99	69.93±1.72	70.54±1.12	72.49±1.26	73.59±1.47	70.83±1.99	*0.0645*
% Pelleted	95.29±1.00[a]	93.85±0.87[ab]	94.48±0.57[ac]	96.71±0.64[a]	98.16±0.74[d]	98.26±1.00[d]	*0.0113*
Through Put Capacity	63.63±4.37a	54.49±3.79b	56.59±2.47ab	59.77±2.78ab	64.15±3.23ab	72.52±4.37ac	*0.0138*

[a, b, c, e, f] Means followed by different superscripts on the same row are significantly different at 5% level.

From the ANOVA table, apart from the pelleting efficiency that was not significant, though it increased with increase moisture content. The rest of the extruder parameters showed significant at p<0.05, with the initial feed weight and pelleting weight been highly significant, P<0.001 with the variation in moisture content.

TABLE 5: Predicted equations of moisture content on extruder performance

PARAMETER	PREDICTED EQUATION		
	Linear Regression	R^2 (%)	P
Initial feed weight	Y = 4.48+ -0.167X	90.29	*0.0037*
Feed Input time	Y = 2.89+ -0.007X	0.01	*0.9856*
Feed pelleting time	Y = 3.89 + -0.002X	0.01	*0.9856*
Pellet weight	Y = 4.28 + -0.154X	91.86	*0.0026*
Total feed input	Y = 102.80 + -4.821X	40.81	*0.1721*
Pelleting efficiency	Y = 95.44 + 0.208X	6.50	*0.6259*
Percent pelleted	Y = 95.44 + 0.208X	32.16	*0.2405*
Throughput capacity	Y = 73.10 + -3.154X	53.36	*0.0992*

**Y-Parameters X- moisture content*

The best prediction equation of moisture content was given by the pellet feed weight and initial feed weight followed by the throughput capacity of the machine, total feed input and percent pelleted. The linear indicated highly significance (p<0.01) effect for the model, intercept and slope of regression line indicating that the traits decreases with increasing moisture content.

6. Discussions

Effect of moisture on extruder performance

From the study it was realised that for both feed, higher moisture values were recorded on feed component (Elephant grass, gliricidia and the cassava with the peel) that had larger particle sizes (3.90mm, 4.14mm and 1.54) and geometric mean diameter (0.76, 0.88 and 0.79) respectively.

The different particle sizes led to the higher mechanical interlocking and surface tension forces that had resulted to the stronger and durable pellets as stated by Pratiksha *et al.* (2012)

The initial feed weight, pellet weight, total feed input, percent pelleted and throughput capacity were highly significant at p<0.01 whilst the input time and pelleting time were also significant at p<0.05 at the various moisture levels, SAS,(2008)

The study also revealed that variation in moisture content has no effect on the percent pelleted feed.

Effect of particle size on extruder performance

It was observed from the study that the initial feed weight, pelleted feed weight and the extruder throughput capacity were highly significant at $p<0.01$ at the different particle size of the raw feed material, while the total feed input was significant at $p<0.05$, SAS, 2008, as observed by Adapa *et al*. (2004) that a decrease in the biomass grind size have a positive effect on pellet throughput. From the study, particle size had no effect on the feed input time, pelleting time, pellet efficiency and percent pelleted.

Effect of type of feed on extruder performance

Apart from the percent pelleted feed, the performance parameters of the extruder were highly significant at $p<0.001$ for the two feed ration, SAS, 2008,

The high contents of crude starch, protein, crude fibre, cellulose and hemi-cellulose of the raw main feed component (elephant grass, gliricidia cassava and the peel and the soy meal increased the pelleted feed strength and durability. The heat and moisture and shear resulted in protein denaturation and this induced the binding functionality of the protein as reported by Wood, 1987; Thomas *et al*. 1998; Winowiski, 1988; Briggs *et al*. 1999.

7. Conclusion and Recommendation

It was realised that the feed material required much moisture to enable them to form pellet due to the high fibre content of the raw materials with the component of larger particle sizes having the highest moisture levels. Generally, the moisture content has significant effect on the machine performance since it is needed for gelatinization of the feed. The water acting both as a binder and lubricant helped to increase the area of contact between the feed particles, and thus resulted in the high pelleting efficiency, percentage pelleted feed and the machine throughput capacity.

It was realised that the machine pelleting efficiency decreased whilst the percentage pelleting increased with increased moisture content of the raw feed mix for both rations with the exception of the two pass of the main component of ration 1 that increased and decreased proportionally with increased moisture content.

The throughput capacity of the machine also increased with increased moisture content during pelleting except the feed of ration 1 (urea inclusive) that decreased from the first moisture levels (47.34 and 60.60%) to the second moisture level (53.25 and 64.95) and latter increased at the third moisture levels. It could therefore be concluded that the presence of urea as a component of the feed unlike the feed with the soy meal has a negative effect on the machine performance.

It was also observed that the main feed component of smaller particle size (two passes through the 2.0mm screen of the hammer mill) gave better machine performance than the one pass that had bigger particle sizes.

The absence of pre-condition with either steam and the use of commercial binder makes the extruder outstanding and easier to use by small and medium scale grasscutter farmer to produce pellet in their homes and to remove the drudgery of transporting, handling and storing large quantities of the forage that need larger storage structures.

Further work be done to determine the idea particle size of the various feed component that will provide higher performance of the extruder.

It is recommended that research be done on feeding grasscutter in captivity with the pellet feed to assess their growth performance and economic viability.

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