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Development and Preliminary testing of a Mixing and Pelletizing Machine for Livestock Feeds Production

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ABSTRACT: Agro crop residues such as cereal, stovers and fodders do not individually contain all the nutrients required for the optimum growth of ruminant animals, hence, the need to bring them together to form a balanced diet. A mixing and pelletizing machine was designed and constructed to mix and pelletize pulverized feed materials (elephant grass, wheat bran, cassava peel, molasses, cassava starch, bone meal, maize stover and groundnut cake). The mixing unit consists of the mixing hopper and a mixing chamber that houses the mixer shaft and the mixing paddles while the pelletizing unit consists of the pelletizer hopper, pelletizing barrel, a shaft with worm thread and die perforation as outlet for the pellets. A preliminary performance test was carried out on the machine to determine the effects of binder condition and moisture content on the throughput capacity and pelletizing efficiency. Three levels of binder conditions (0 kg, 0.5kg and 0.9 kg of molasses) and five levels of moisture contents (20, 22, 24, 26 and 28% (dry basis)) were used. The results showed that the highest throughput capacity and pelletizing efficiency were 116.12 kg/h and 86.76 % at a moisture content of 26 % (db) respectively. From the proximate analysis done, samples with 0.9 kg molasses generally had the highest amount of ash content, crude fibre, crude protein and crude fat. This machine would enhance the availability of nutritious pelletized feedstock for ruminant animals all year round.

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Majority of small ruminant farmers in Nigeria practice the extensive system of management which does not make provision for adequate feeding. In northern region of Nigeria where most of the Nation's livestock are concentrated, dry season last between six to nine months. This often causes serious feed shortages for the animals. This dry season and high temperatures are also accompanied by rapid deterioration in the nutrient quality of the available pasture, hence the basic nutritional requirements of the animals during pregnancy or lactation are not met (Glatzle, 1991). Ruminant animals however differ from other livestock in that their rumen enables them to make use of feedstuff such as crop residues or cereal stovers. These are inexpensive, readily available, of no direct importance in human nutrition, and are often regarded as environmental nuisance after harvest and processing of crops (Aregheore and Chimwano, 1992). It has been observed that the rate of livestock production in Nigeria is not commensurate with human population growth and demand as a result of the poor feedstock (Aregheore, 1996). A major problem facing livestock producers is how to provide a balanced nutrition for their animals, especially during the dry season when pasture and cereal residues are limited in quantity and nutritional quality. The agro crop residues such as cereal and fodders are not individually balanced feed for ruminant animals, hence, the need to bring them together in order to have optimum production of the animals (Aregheore and Chimwano, 1992). Pelletization process is an alternative means of providing pasture and feedstock in adequate proportion to grazing animals. Feed pellets will increase the bulk density and palatability of feeds to livestock. It will also reduce wastage of feeds, ingredient segregation and selective feed consumption. A livestock feeds pelletizing machine was developed and tested by Orisaleye *et al.* (2009). The pellets formed had density value varying from 0.7 and 1 g/cm^3.The throughput capacity varied from 3.21 kg/h to 4.32 kg/h. An extruder for fish feed was designed and constructed by Odesola *et al.* (2016). The diameter of the pellets produced by extruder varied from 3 to 5 mm. The throughput capacity of the machine was 300 kg/h. An animal feed mixing machine was designed, fabricated and tested (Makange *et al.* 2016). The average degree of mixing achieved was 94.06 % while the average coefficient of

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variation was 5.93 %. The few imported pelletizing machine are either poultry feeds or fish feeds. Availability of a mixing/pelletizing machine using crop residues for ruminant animal feeds has not been reported. Also, the available machines in livestock industry are either mixer or pelletizer as single machine. Bringing them together as a single unit will enhance operational efficiency and lower cost of production. Hence, the objective of this research work was the development of livestock feeds mixer and pelletizer which use crop residues and other ingredients as raw materials.

MATERIALS AND METHODS

Design Considerations: In carrying out this design work, effort was directed towards obtaining a system that would give the desired compactness. The dimensions of the various components were calculated to minimize size and weight of the machine and at the same time not compromising the standard strength and efficient functioning of the various parts. The physical and mechanical properties of the feed materials were also considered as these played a vital role in the pelletizing process. Other criteria that were considered were angle of repose and homogeneity of the mixed feed to achieve free flow and balanced ration for the animals.

Description of the Machine Components: The mixing and pelletizing machine comprises of the hopper, mollases container, mixing chamber and pelletizing barrel. The remaining components are as shown in figure 1.

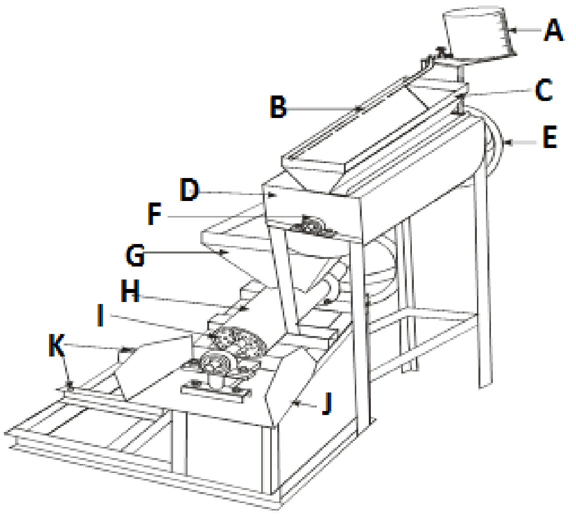

Fig 1: Isometric view of the machine

Where A= Molasses/water container, B = Pipe/Hose Connection, C = Hopper (mixer), D = Mixer, E = Pulley, F = Bearing, G = Hopper (Pelletizer), H = Pellet Barrel, I = Die perforation, J = Pellet collecting trough, K = Electric motor seat,

Design Calculations

Capacity of the Mixer and Pelletizer Hoppers: The hopper design of the mixer was based on the volume of a trapezoidal prism. Since elephant grass was the major base material for the pellet formation, the properties of elephant grass were used for the hopper design. Also, the hopper design for the pelletizer was also based on the volume of a trapezoidal prism. The volume of hopper was calculated from the relationship in equations (1) and (2).

Bulk Density of Elephant grass = 560 kg/ m^3 (Edgardo *et al.*, 2012)

$$Density\ (d) = \frac{mass\ (m)}{volume\ (v)} \quad (1)$$

The volume of materials that would be contained in the hopper was derived from equation (1). The volume of the trapezoidal hopper was calculated using the formula given by John (2005).

$$V = 0.5\ (a + b) \times h\ \times l \quad (2)$$

Where V = Volume of hopper; *a* = Top width of hopper; *b* = Bottom width of hopper; *l* = Side length of hopper and *h* = Vertical height (m).

Determination of the capacity of the Mixing Chamber: The capacity of the mixing unit was needed to determine the quantity of material that the mixing unit could contain at once. Therefore, the volume of the mixing unit was determined using the formula for calculating the volume of a cylinder (equation 3) as reported by John, (2005).

$$V = \pi r^2 H \quad (3)$$

Where V = Volume of material to be mixed (m^3); r = radius of mixing unit (m) and H = Length of mixing unit (m).

Determination of the Mixer and Pelletizer Shaft Diameter: This was done to determine the size of the shaft diameter that would withstand the applied loads. For a solid shaft with little or no axial load, the diameter of the shafts was determined using the relationship equation (4).

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (4)$$

Where d = the diameter of the shaft (m); S_s = Allowable stress = 40 × 10^6 Nm^{-2} (Hall *et al.*, 1980); K_b = Combine shock and fatigue factor applied to bending moment (Nm); M_b = Bending moment (Nm);

K_t = Combine shock and fatigue factor applied to torsional moment and M_t = Torsional moment (Nm).

Determination of Pulley Diameter for the Mixer and Pelletizer: The pulleys were designed by considering the power to be transmitted between the electric motor and the mixing and pelletizing units. In addition, the drive motor speed was stepped down via a gear reducer system having a gear ratio of 1:2. The allowable diameter of the pulley was calculated using equation (5) by Khurmi and Gupta (2005). Neglecting belt thickness,

$$N_1 D_1 = N_2 D_2 \qquad (5)$$

Where N_1 = Speed of the electric motor pulley (rpm); D_1 = Diameter of the electric motor pulley (mm); N_2 = Speed of the mixer shaft (rpm) and D_2 = Diameter of the mixing shaft pulley (mm).

Determination of the Internal Diameter of the Pelletizing Barrel: The relationship between the screw (flight worm) diameter and the internal diameter of the pelletizing barrel can be expressed as given by Mrema and McNulty (1985). A Screw (worm) diameter of 82 mm as recommended by Singh (2003) was used to calculate the internal diameter of the pelletizing barrel by the equation (6).

$$D_p = \frac{D_\mathrm{i}}{1.04} \qquad (6)$$

Where D_p = Screw (flight worm) diameter (mm) and D_i = Internal diameter of cylinder (mm)

Determination of the Pressure needed for Pelletization: The pelletizing barrel is considered as a thick cylinder under pressure exerted by the rotational and compressing actions of worm shaft. Preliminary tests were carried out on the compressive force required to compress feedstock into pellets using the Universal Testing Machine (Model No: FS300CT) in the Departmental laboratory of Agricultural and Biosystems Engineering, University of Ilorin. The maximum compressive (pelletizing) force from the test was approximately 72kN. The pelletizing force was used to calculate the pelletizing pressure with respect to the area of the pelletizing barrel. To determine the pelletizing pressure required for pellet formation, the formulae given by Ramsdale (2006) as shown in equation (7) was used:

$$P = \frac{F}{A} \qquad (7)$$

Where F = Pelletizing Force = 72 KN (determined); P = Pelletizing Pressure (MPa); A = Area of the pelleting barrel (m^2) and D_i = Internal diameter of the pelletizing barrel (mm)

Determination of the Power Requirement of the Machine: The power requirement of the machine was a combination of the power required to operate the mixer and the pelletizer. The power requirement of the pelletizer was the power required to drive the screw shaft for pellet formation while the power required by the mixer was the power required to produce a homogenous mixture of the feed materials. The power requirement of the pelletizer was calculated with the formulae given in equation (8) and (9) by Singh (2003).

$$P = \frac{QL\,(W_0 + \sin\beta)}{3600\eta} \qquad (8)$$

But

$$Q = 150\pi D^2 \sin\psi p C \quad (\mathrm{Singh}, 2003) \qquad (9)$$

where, P = Power requirement of the machine (kW); Q = Capacity of the Screw Conveyor (kN/h); D = Nominal screw diameter (mm); ψ = Loading efficiency = 0.25 (Constant) (Galen *et al.*, 2008); C = Factor of inclination = 1 (Constant); $\rho =$ Maximum density of material to be pelleted = 700 kg/m^3 (Galen *et al.*, 2008); L= Length of the Screw Conveyor (mm); W_o = Material Factor = 4 (Constant); $\beta =$ Angle of inclination of screw to the horizontal = 0; and $\eta =$ Efficiency of speed reduction system

The screw conveyor was a worm wound round a cylindrical shaft. The maximum outer diameter of the worm was obtained as 82 mm to give clearance between the screw and barrel. The parameters obtained were as reported by Singh (2003). The power required to mix the various materials for the pelletizing operation was calculated using the equation 10 as specified and cited by Singh (2003).

$$P_m = T\omega \qquad (10)$$

where, P_m = Power requirement of the mixer in (kW); T = Torque of the mixer paddle (kNm) and ω = Angular velocity of the mixer paddle in rad/s

Detailed Orthographic projection of the machine is shown in figure 2.

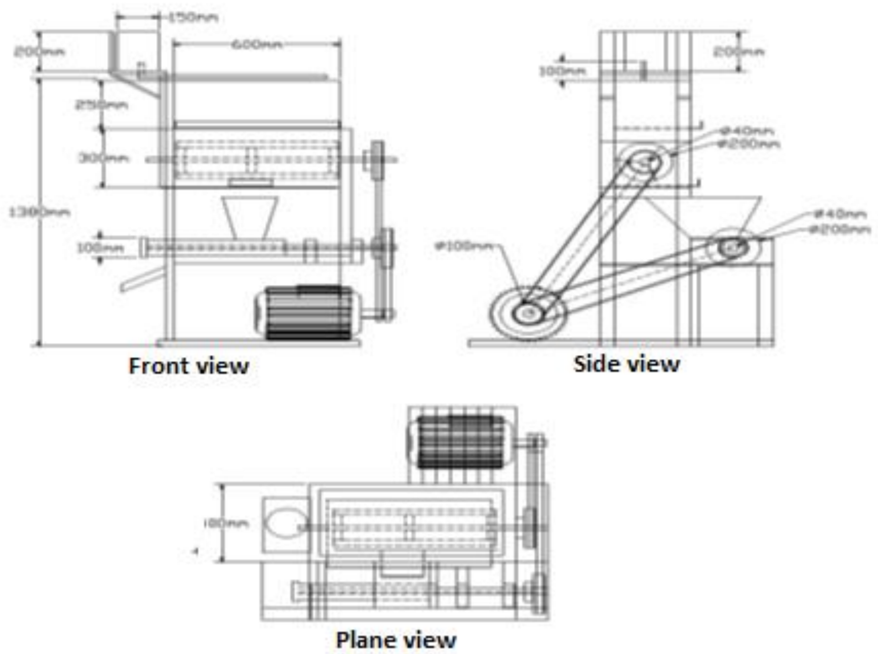

Fig 2. Orthographic Projections of the Machine

Performance Evaluation of the Mixing and Pelletizing Machine: The operational performance of the developed mixing and pelletizing machine for livestock (ruminant) feed was carried out to determine the effects of binder condition and moisture content on the throughput capacity and pelletizing efficiency. Three levels of binder conditions and five levels of moisture contents were used. The feedstock comprised of 0.88 kg of Elephant Grass, 0.27 kg of Maize Stover, 0.17 kg each of Cassava Peels, Cassava Starch, Cassava Starch, Wheat Bran, Bone Meal, and Groundnut Cake. These materials were cleaned and pulverized using a hammer mill of 3 mm screen aperture to form a mash as recommended by Karkania *et al.* (2012). The pulverization process (size reduction) was to accelerate the pelletization process. The mash was dried to achieve initial moisture content of 10 % (dry basis). The binder conditions were 0 kg, 0.5kg and 0.9 kg of molasses as binder. Sample of 2kg of feedstock was conditioned at a time to obtain each final moisture content of 20, 22, 24, 26 and 28% (dry basis). Equation (11) as given by Adejumo and Abayomi (2012) was used to obtain the quantity of water to be added to achieve the desired final moisture content (db). The machine was run at constant machine speed of 800 rpm. The performance test was repeated three times for each treatment combination of binder condition and moisture content level.

$$Q = W_t\left(\frac{M_f - M_t}{100 - M_f}\right) \qquad (11)$$

Where Q = quantity of water added (kg); W_i = initial weight of the sample (kg); M_f = final moisture content (%) db; M_i = initial moisture content (%) db.

The equations used for the Throughput capacity and pelletizing efficiency were as follow:

i. *Throughput of Machine*(T_m): It is the ratio of the weight of extruded pellets to the total time taken to extrude the pellets expressed in kg/h and is given as:

$$T_m = \frac{W_g}{t} \qquad (12)$$

Where T_m= Throughput Capacity of Machine (Kg/h); W_g= Weight of extruded pellets (Kg) and
t = Total time taken to extrude the pellets (h)

ii. *Pelletizing Efficiency:* This is the ratio of the weight of pellet formed to the total weight of mash fed into the pelletizer and was evaluated using the formula below:

$$P_e = \frac{X_a}{X_b} \times 100 \qquad (13)$$

Where P_e = Pelleting efficiency (%); X_a = Weight of formed pellets obtained (kg) and X_b = Weight of mash fed into the pelletizer (kg).

The results obtained were analyzed using Duncan's New Multiple Range Test (DNMRT) in order to know the significant difference between each level of treatment factors at 5% confidence level. The effects of moisture contents on Throughput capacity and Pelletizing efficiency were determined. Proximate analysis was conducted on the samples to determine their nutritional properties. Also, drying profile for the pelletized feedstock at each binder condition was derived.

Principle of Operation of the Machine: The developed mixing and pelletizing machine was powered by a 5 hp electric motor. Dried feed constituents at specific moisture contents were ground with binder (molasses) in the mixing unit for a period of 10 minutes to achieve a uniform mix. The slurry material formed was then fed into the pelletizer hopper by opening the aperture on the lower end of the mixing chamber. The formed slurry flowed freely by gravity into the pelletizing unit of the machine where the actual pelletizing job took place. The extrusion process which produced the pellet was facilitated by the rotary action of the screw press that compressed the slurry against the die plate at one end thereby leading to the extrusion of pellets.

RESULTS AND DISCUSSION

The technical specifications of the designed mixing and pelletizing machine are presented in Table 1. Figure 3 shows the pictorial view of the completed mixing and pelletizing machine. The machine was fabricated with steel material which is locally available, cheap and provide the adequate strength and rigidity needed by the designed machine.

Table 1: Technical Specifications of the Designed Mixing and Pelletizing Machine

Item	Specification
Volume of the Mixer Hopper	$1.8 \times 10^{-2} \text{m}^3$
Volume of the Pelletizer Hopper	$2.7 \times 10^{-2} \text{m}^3$
Pulley diameter for pelletizer	200 mm
Shaft Diameter of Mixer	38 mm
Shaft diameter of Pelletizer	40 mm
Power requirement	3.48 kW

Fig 3. Pictorial View of the completed mixing and pelletizing machine

Effect of Moisture Content on Throughput capacity and Pelletizing efficiency: The results of effects of moisture content on the throughput capacity and pelletizing efficiency are presented Table 2. The results obtained showed that the highest throughput capacity of the machine was recorded as 116.12 kg/h at a moisture content of 26 % (db) while the lowest throughput capacity was recorded as 88.64 kg/h at a moisture content of 20 % (db). It was observed that the throughput capacity increased as the moisture content increased except that it dropped at moisture content of 28 % (db). At low moisture content (20 %) (db), there seem not to be enough moisture to bind the feed constituents together as such leading to a low throughput capacity. Very high moisture content (28 %) (db) does not favour high throughput capacity also because it inhibits proper ejection of formed pellets. This trend is similar to what was reported by Ojomo *et al.* (2010) that claimed that as moisture content increases from 3 to 15 %, throughput capacity also increases from 5 to 20 kg/h for their machine. The highest pelletizing efficiency of the machine was 86.76 % at a moisture content of 26 % (db) while the lowest pelletizing efficiency was 70.90 % at a moisture content of 20 %(db). Table 2 reveals that as moisture content increased the pelletizing efficiency also increased but started to decline at moisture content of 28 % (db). As the moisture content increased, the binding force for the feed constituents also increased for proper pellet formation and ejection. Very high moisture content (28 %) (db) does not favour pelletizing efficiency because it inhibits proper formation of the pellets. The results obtained is in agreement with the claim of Ojomo *et al.* (2010). It was reported that as moisture content increased from 3 to 15 % (db), pelletizing efficiency also increased from 10 % to a maximum of 87.56 % for their pelletizer.

Table 2. Effect of Moisture content on Throughput Capacity and Pelletizing Efficiency

Moisture content (db)	Throughput Capacity (kg/h)	Pelletizing Efficiency (%)
20	88.64 ± 0.11	70.90 ± 0.17
22	95.10 ± 0.07	82.71 ± 0.09
24	108.73 ± 0.23	86.10 ± 0.07
26	116.12 ± 0.27	86.76 ± 0.05
28	89.91 ± 0.56	83.87 ± 0.67

Mean value ± Standard deviation; Sample were obtained at binder condition of 0.5 kg molasses and Machine speed of 800 rpm

Proximate Analysis of the produced pellets: Results obtained from proximate analysis conducted on selected samples of the pellets formed by the machine on the basis of binder condition are shown in Table 3. From the table, samples with 0.9 kg molasses generally had the highest amount of ash content, crude fibre, crude protein and crude fat. However, the lowest amount of carbohydrate (50.70 %) was recorded for the samples with 0.9 kg molasses. On the whole, samples with 0 kg molasses generally had the lowest amount of ash content, crude fibre, crude protein and crude fat except for carbohydrate. The highest amount of carbohydrate (53.16 %) was recorded for the samples with 0 kg molasses. Generally, the crude protein content of all the samples were observed to be higher than the common minimum of 7.7 % by NRC (2001) and 7.0 % by Minsson (1990). The carbohydrate content of the produced pellets was observed to be higher than the 44 % minimum level suggested by NRC (2001).

Table 3. Proximate analysis of selected samples of the Pellets

Nutrient %	**Binder Conditions**		
	no molasses	0.5 kg of molasses	0.9 kg of molasses
Ash	4.84 ± 0.01	5.04 ± 0.03	5.08 ± 0.02
Crude Fibre	8.27 ± 0.04	8.27 ± 0.13	8.44 ± 0.02
Crude Protein	19.38 ± 0.07	20.16 ± 0.02	20.45 ± 0.02
Crude Fat	5.74 ± 0.12	5.84 ± 0.04	6.21 ± 0.03
Carbohydrate	53.16 ± 0.56	51.47 ± 0.12	50.70 ± 0.06

Mean value ± Standard deviation; Sample were obtained at moisture content = 22 % (db) and Mixer speed = 800 rpm

Drying Profile pellets according to binder condition: The drying time at different binder conditions are shown in Figures 4 to 6. Drying time is the time taken in drying the pellets from each treatment combination to a stable moisture content that is safe for storage. Figure 4 revealed that the drying time to attain stable moisture content was 2 hours 30 minutes for the pellets formed from 0 kg binder condition. Both Figures 5 and 6 revealed that the drying time to attain stable moisture content was 3 hours. Generally, it was observed that as the binder content increased the moisture content increased and hence the drying time also increased.

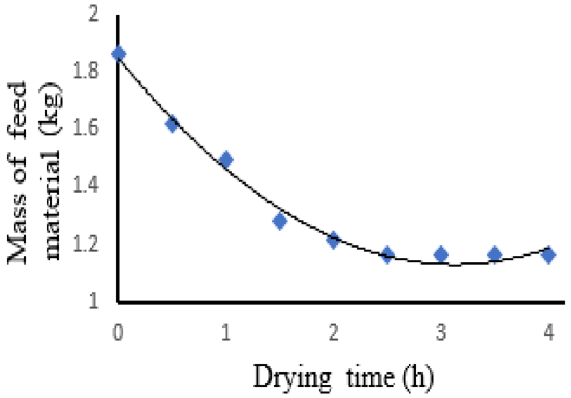

Fig 4. Drying Profile at binder condition of 0 kg molasses

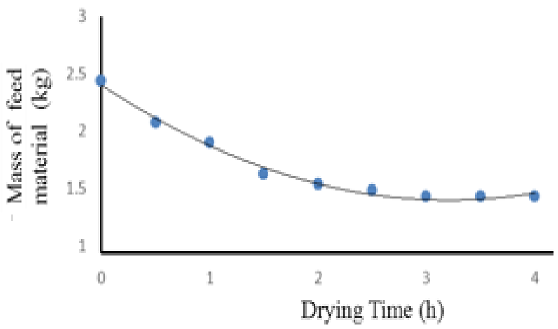

Fig 5. Drying Profile at binder condition of 0.5 kg molasses

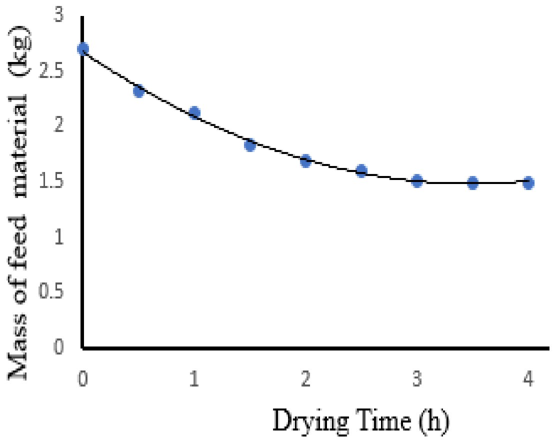

Fig 6. Drying Profile at binder condition of 0.9 kg molasses

Conclusions: A Mixing and Pelletizing machine was designed, constructed, and tested. It has a mixing unit and a pelletizing unit. The performance evaluation results showed that the highest throughput capacity and pelletizing efficiency were 116.12 kg/h and 86.76 % at a moisture content of 26 % (db) respectively. From the proximate analysis done, samples with 0.9 kg molasses generally had the highest amount of ash content, crude fibre, crude protein and crude fat. This machine would help to mitigate the problems of unbalanced nutrition in feeding ruminant animals.

REFERENCES

Adejumo, BO; Ayobami, DA (2012). Effect of moisture content on some physical properties of Dika Nut (Irvangia gabonesis) at two moisture levels as relevant to it processing. *Int. J. Eng. Res. Appl.* 3(2), 182-188

Aregheore, FM (1996). Voluntary intake and nutrients digestibility of crop residues base rations by goats and sheep. *Small Ruminant Res.*, 22:7-12.

Aregheore, EM; Chimwano, AM (1992). Crop residues and Agro by products in Zambia: Availability, Utilization, and potential value in ruminant nutrition. *Proceedings for joint feed res. Netw. Workshop in Gaborone, Bostwana, 1991.* (233-238).

Edgardo, OG; Luís ABC; Guillermo, RA; George, JM; Vinicius, FNS; Eduardo, A. (2012). Some simplified geometrical properties of elephant grass and sugarcane trash particles. *Fuel Proc. Tech.* 104: 234–244.

Galen, R; Rob, S; Brian, P (2008). Pelleted Livestock Feed Production – Process Description, Retrieved March 3, 2008 from http://www.engormix.com

Glatzle, A (1991). Feed resource in the Sahel. *Ani. Res. Devt.* (35):43-58.

Hall, AS; Hollwen, KOA; Laughum, H (1980). *Schaum's outline of theory and Problem of machine design.* Metric Selection.McGrac-Hill Books Company. New York, USA.

John, B (2005). Basic Engineering Mathematics. 4th edition. Linacre Publishing House, Jordan Hill. Great Britain.

Karkania, V; Fanara, E; Zabaniotou, A (2012). Review of sustainable biomass pellets production – a study for agricultural residues pellets' market in Greece. *Renew. Sust. Ener. Rev.* (16): 1426–1436.

Khurmi, RS; Gupta, JK (2005). Machine Design, 14th Edition. S. Chand and Company Ltd., Ram Nagar, New Delhi- 110055. Pp 434-960

Makange, NR; Parmar, RP; Sungwa, N (2016). Design and Fabrication of an Animal Feed Mixing Machine. *Adv. in Life Sci.* 5(9): 3710 – 3715.

Minsson, DT (1990). Forage in Ruminants Nutrition 1st Edition, Academic Press, New York.

Mrema, GC; McNulty, PB (1985). Mathematical model of mechanical oil expression from oilseeds. *J. Eng. Res.* 31:361-370

NRC (National Research Council) (2001). Nutrient requirement of Goats. Angorra, diary and meat goats in temperate and tropical countries. Nutrient requirement of domestic animals No 15 NRC Washington DC, USA.

Odesola, IF; Kazeem, RA; Ehumadu, NC (2016). Design and construction of a fish feed extruder. *Int. J. Sci. Eng. Res.* 7(8): 1378 - 1386.

Ojomo, AO; Agbetoye, LAS; Ologunagba, FO (2010). Performance Evaluation of a Fish Feed Pelletizing Machine. *ARPN J. Eng. Appl. Sci.* 5(9): 88 – 97.

Orisaleye, JI; Ojolo, SJ; Fashina, AB (2009). Design and development of a livestock feed pelleting machine. *J. Eng. Res.* 14(1): 1 - 9.

Ramsdale, R (2006). Reference Tables: Fluid Power Formulars. Retrieved January 26, (2016) from http://www.engineershandbook.com/Tables/fluidpowerformulas.html

Singh, S (2003). Khanna's Mechanical Engineers Handbook, 2nd edition, Khanna Publishers, Delhi.