

DEVELOPMENT AND EVALUATION OF CORN STALK SHREDDER FOR ANIMAL FEED

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ABSTRACT

Nigeria's livestock population is one of the largest in Sub-Saharan Africa, however different factors limits the full exploitation of the various agricultural sectors especially the livestock sub sector. The availability, quality and quantity of livestock feed has always been a challenge. Poor feed management, especially those of the bulky and fibrous crop residue is one of such constraints. Manual crop residue slicing is part of crop residue management as practiced by most livestock farmers is one of such management practices. This process is laborious, expensive and time consuming. To alleviate this, a Corn Stalk Shredder was designed, developed and its performance was evaluated using corn stock. Prime mover speed, feed rate and feed thickness were varied using factorial design with three replications. Results obtained shows that the maximum mean shredding capacity of the shredder of 558.32 kg/h was attained when the shredder was fed by 6 kg of corn stalks with an average thickness of 250 mm at a speed of 2500 rpm. The study revealed that the interactions of this parameter were also significant on the capacity of the shredder but were not significant on the size of the feed stalks. It also indicated that the operational speed of the shredder was significant on the length of cut of the shredded corn stalks. It is recommended that crop residue to be shredded should be kept at the optimum storage temperature of the crop.

Keywords: Animal Feed, Corn Stalk, Livestock, Shredder

1 INTRODUCTION

The livestock subsector has always been an important component of the Nigerian economy. It provides employment and income for a large proportion of the rural population especially in the northern part of the country. Animal production is very essential to the nation's food security [1, 2]. Livestock is as an important source of protein in the diet and also provides raw materials for the clothing and shoe industry and by-products can be used in various other industries such as the cosmetic industry. Livestock contributes significantly to the national economy, accounting to about 5.55% of the overall GDP of the Nigeria as at first quarter of 2022. However, despite the importance of the subsector, growth in livestock output has been dawdling [3, 4]. Livestock production in Nigeria remains a traditional activity carried out under pastoral and agro-pastoral systems in the north and mixed farming systems in the south. Under the pastoralist system, animals are managed within nomadic or transhumance herding systems. With the rapid increase of human population and increasing demand for food, grazing lands are steadily shrinking by being converting arable lands to areas that have little agricultural value [5]. Other challenges in the livestock production includes lack of feed resource, equipment and input that would improve quality, feed quantity, post-harvest handling, ecological deterioration, overgrazing, lack of seed and planting materials

[5, 6]. However, the main constraint to increased production in the traditional pastoral system is the nutritional stress experienced during the dry season from January to March. This often necessitates seasonal migrations in search of pasture. Apart from the hardship imposed on the animals, migration often resulted in conflicts with crop farmers who complain that the migrating animals eat and damage their crops [7]. Animal feeds play a leading role as one of the most crucial contributors in ensuring safe, abundant and affordable animal protein [8, 9]. Efficient, intensive production of meat, milk and other foods requires balanced feeds. Provision of feed that is adequate both in quality and quantity and accessible to animals all year round is the most outstanding problem of livestock production in Nigeria. The natural range resources that form the primary source of nutrients have been observed to rapidly increase in nutritive value at the onset of rains and decline shortly thereafter. The state of poor nutritive feed quality often lasts longer during the year than the period of forage abundance and high nutritive quality. Supplementation with crop residues from cropped farmlands scarcely meets the requirements for animal growth [10]. The cyclical occurrence of feed deficit year in and year out impairs animal growth rate and reproductive performance while instigating movement of stock from one place to another with its numerous attendant problems including high susceptibility of animals to diseases and pest attack and often fatal clash between herders and farmers [11, 12, 13]. Due to the scarcity and high cost of feeds various research alternatives have been sought for other means of providing animal feeds to ameliorate the effects of cost of feed such as the use of activated sludge [14]. Many livestock and poultry farmers compound their own feed themselves for their farm animals but they face the challenges of raw materials for compounding the feed which may be very expensive or unavailable [15]. The essence of feed formulations is for maintaining or improving nutritive value (increasing digestibility and nutrient accessibility), preventing feed spoilage, isolating specific components from feeds and improving handling efficiency, reducing wastage. Traditionally, pastoral system in Nigeria is associated with feeding livestock with raw and unsliced crop residues (corn stalks and other remnants). This system is not only wasteful, health hazardous and labourious, but also time consuming since primitive tools are mostly used in cutting the stocks into shorter length [16, 17]. To overcome these challenges encountered in the livestock production with respect to the availability, quality and quantity of animal feed in the country, a corn stalk shredder was designed and developed in the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria that could be used in slicing agricultural stalks in order to minimize wastage and drudgery in providing suitable pasture for optimum and profitable livestock production.

2 METHODOLOGY

The corn stalk shredder was designed and developed in the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. The design was based on the local availability of the materials, ease of operating and maintenance and affordability to low income and small-scale farmers. The major components of the shredder include stalk inlet, shaft, shredding/cutting blades, housing, frame, power source and sliced stalk outlet (Figure 1).

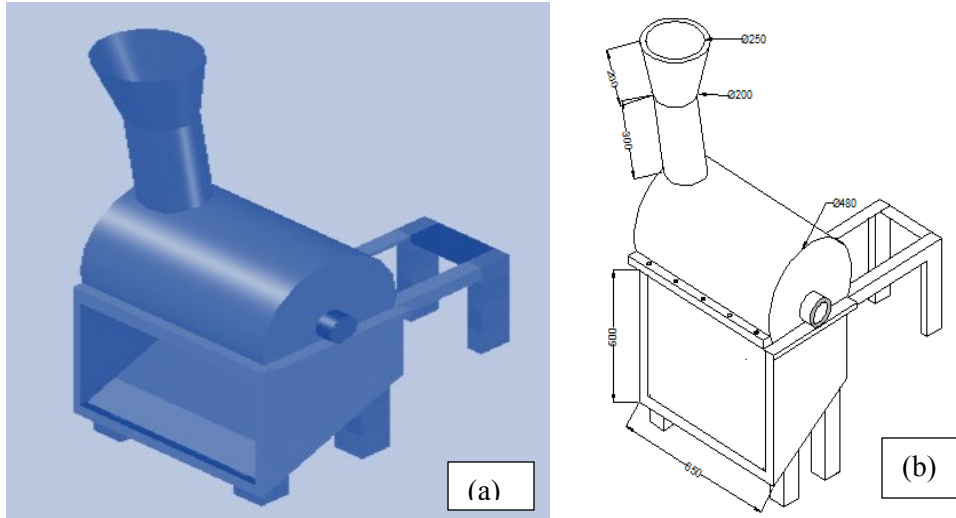


Figure 1. (a) CAD Drawing (b) Schematic Drawing of the Developed Corn Stalk Shredder

Frame: The frame is considered as the backbone of the shredder that supports all the functional parts of the machine. It was designed to withstand rigours of the shredding mechanism as well as the vibrations of the prime mover. Its dimension is 650 mm in long, 350 mm in wide, 650 mm in high. The construction material is 2 mm angle iron (Figure 2).

Stalk inlet: This is the part of the shredder where the corn stalk is fed into the machine. It acts as the hopper of the shredder that transmits material to be shredded into the blade housing. The cutting material is fed manually through the hopper from the top side. The upper dimensions of the hopper are 250 mm diameter and 200 mm length, while the lower part has 200 mm diameter and 300 mm length (Figure 1b).

Screen: The screen is the part of the shredder through which the shredded corn stalk would be collected. It was made from 2 mm galvanized sheet (Figure 2).

Shaft: This is the part of the machine that holds the shredding/cutting blades. It also serves as the source of power transmission from the prime mover to the shredder. It is made up of a 40 mm diameter, 680 mm functional length and 780 mm overall length mild steel rod to accommodate the roller bearings the connects it with the frame and the prime mover (Figure 3).

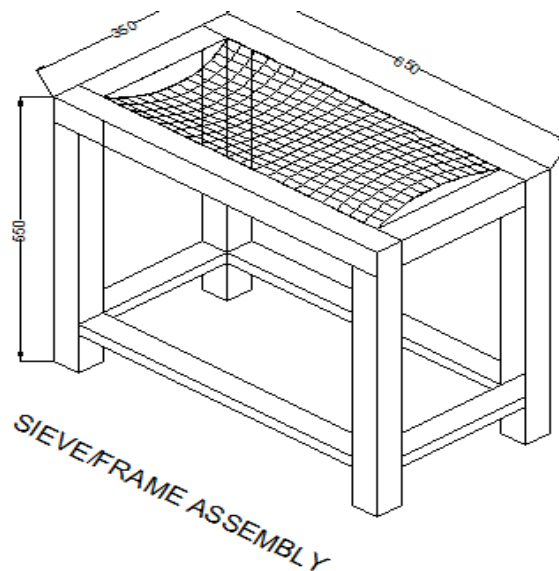


Figure 2. Frame and Screen Assembly

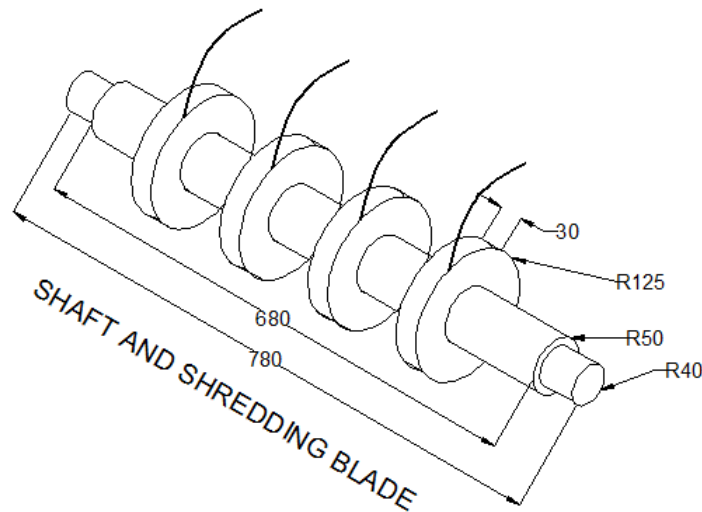


Figure 3. Shaft and Shredding Blades Assembly

Shredding/Cutting blades: The blades do the actual shredding of the corn stalks fed into the shredder. It is made of spring material that would be able to withstand shock. The blades are designed to cut the feed to the recommended lengths with reasonable consistency (Figure 3).

Housing: This is the unit which houses and supports all the functional units. It is made of 3 mm mild steel with a diameter of 480 mm and a length of 650 mm.

Prime mover and power transmission assembly: The shredder is powered by a 5hp diesel engine that is being transmitted through the belt, shaft and pulley for its operation.

Materials and instrumentation: Materials and instruments used in evaluating the shredder includes the corn stalk, 100 kg weighing scale, stopwatch, Vernier caliper with 0.5-mm precision, jute bags, digital camera, wrenches and pen and papers for recording data observed.

2.1 Principles of operation of the shredder

The shredder is powered by a 5hp diesel engine. The prime mover was fitted with a pulley of 100 mm diameter to drive the shredder by a 150 mm pulley through a V-belt mechanism. The power transmitted drives the shredding assembly through the shaft. The shaft then rotates the dynamic shredding blades that were attached to the shaft. While the corn stalk is inserted through the hopper, the shredding blades will cut the material through the rotary action of the shaft. Corn stalk or any other material fed and shredded would then be filtered by a filter plate or screen at the bottom of the shredder where the product is collected. Screening size is a hole of 5 mm in diameter and 10 mm length.

2.2 Evaluation Procedure

The corn stalks used for the evaluation of the shredder was obtained from the Experimental Farm of the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria. Stem samples of the selected determine for the study were weighed on the weighing balance. The humidity, sizes and eight indicators of the sampled stalks were also determined. Parameters evaluated were its capacity, work quality (shredding/cutting length) and efficiency. Factorial experimental design with three replications and Analysis of Variance (ANOVA) were used to determine the differences among the treatment means. The variables of the study were the prime mover seed, feed rate and the thickness of the corn stalks. Two different prime mover speeds 1500 and 2500 rpm, two different feed rates 3 and 6kg and two different average stalk thicknesses 250 and 350 mm were varied to evaluate the shredder. Two sets of corn stalk thicknesses of 250 and 350 mm were varied during the evaluation process. The respective weights of the three trials were 5, 10 and 15 kg from a total of 18 samples. At the first trial, the shredder was run at a speed

of 1500 rpm shredding the first 9 samples, then the shredder speed was adjusted to run at 2500 rpm to shred the remaining 9 samples. The average time taken, fuel consumption and the sliced samples for each test were recorded. The average lengths of the sliced samples were also recorded. The speeds of the shredder were adjusted by alternating suitable pulleys on the main shaft of the shredder as suggested by Mamatoy *et al.* [18].

2.3 Determination of the theoretical and actual lengths of sliced corn stalks

The theoretical lengths of cut of the sliced corn stalks (L_{th}), slicing efficiency and slicing capacity were determined as suggested by Srivastava *et al.* [19].

$$L_{th} = \frac{60000V_f}{\lambda_k n_c} \quad (1)$$

where: L_{th} = Length of cut of sliced corn stalk, V_f = Feed velocity (m/s), λ_k = Number of knives on the shaft, and n_c = Rotational speed of the shaft (rpm). At the end of each slicing process, random samples were taken from sliced corn stalks to be categorized into small, medium, and large in order to determine the actual mean of slicing length (L_{ac}).

2.4 Determination of slicing efficiency

The cutting efficiency of the shredded corn stalks was determined as:

$$\eta_s = \frac{L_{ac}}{L_{th}} \times 100 \quad (2)$$

where: η_s = Slicing efficiency; L_{ac} = Actual length of the sliced corn stalk (mm), and L_{th} = Theoretical length of the sliced corn stalk (mm).

2.5 Determination of the shredder capacity

The theoretical capacity of the shredder (T_{th}) was determined from equation 3.

$$T_{th} = \frac{\rho_f A_t L_c \lambda_k n_c}{6 \times 10^8} \quad (3)$$

where: T_{th} = Theoretical capacity of the shredder (kg/s); ρ_f = Density of corn stalk in the slicing chamber (kg/m^3); A_t = Theoretical area (cm^2); L_c = Theoretical length of cut (mm); λ_k = Number of knives on cutterhead, and n_c = Speed of main shaft of the shredder (rpm).

3 RESULTS AND DISCUSSION

The shredder was designed, constructed (Figures 4 to 6) and evaluated.



Figure 4. Front and Rear Sides of the Developed Shredder



Figure 5. Frame and Screen Assembly of the Developed Shredder



Figure 6. Shaft and Shredding Blades Assembly of the Developed Shredder

Results from the study shows the analyses of the data obtained after the shredder was evaluated (Tables 1 to 4). Parameters evaluated were the mean values of the cutting lengths, the efficiency of the shredder, rate of shredding and amount of fuel consumed. Table 1 show the mean values of cutting lengths (mm) and efficiency (%), rate of shredding (kg/h), efficiency of the shredder (%) the amount of fuel consumed (l/h) while Tables 2 to 4 represents the analysis of variance (ANOVA) to determine the differences among the treatment means. Results obtained shows that the maximum mean shredding capacity of the shredder was 558.32 kg/h) was attained when the shredder was fed by 6 kg of corn stalks with an average thickness of 250mm at a speed of 2500 rpm. However, the finest mean length of the shredded corn stalks was 8.43 mm was obtained when the when the shredder was fed with 6kg corn stalks of 350mm thickness at a rated speed of 2500 rpm. The also shows that the maximum slicing efficiency of 92% was attained at on operational speed of 2500 rpm when the shredder was fed with 3kg corn stalks of 250mm thickness. Similarly, the mean least fuel consumed of 0.51 was obtained while the machine was fed with 3kg corn stalks of 350mm thickness at an operational speed of 2500 rpm.

Table 1. Parameters of the shredder evaluated

Treatment	Corn Stalk Thickness (mm)							
	250				350			
	Operating Speed (rpm)							
	1500		2500		1500		2500	
Feed rate (kg/h)								
	3	6	3	6	3	6	3	6
Cutting length (mm)	12.03	10.89	12.21	8.46	10.93	12.59	8.61	8.43
Slicing efficiency (%)	86	88	92	89	85	83	91	89
Shredder capacity (kg/h)	241.92	288.01	492.34	558.32	238.92	309.19	545.86	553.97
Fuel consumed (l)	0.71	0.89	0.93	0.98	0.81	0.64	0.51	0.95

Tables 2 to 4 represents the analysis of variance (ANOVA) that climaxed the differences among the mean treatments conducted in the study. The differences (variabilities) observed in the performance of the shredder does not actually depend on the number of replications of the treatments but were dependent of the treatment itself (Table 2). The study also revealed that the capacity of the shredder was dependent on the operational speed of the shredder. However, the effects of the operational speed of the shredder and the rate of feeding the shredder were observed to be highly significant on the capacity of the shredder (Table 3). The interactions of these parameter were also significant on the capacity of the shredder but were not significant on the size of the feed stalks. The study also indicated that the operational speed of the shredder was significant on the length of cut of the shredded corn stalks (Table 4).

Table 2. Analysis of variance for treatment Vs replication

Parameter	Df	Sum of Square	Mean Square	F-value	Pr(>F)
Treatments	7	558724	79814	88.6713	4.560e-11***
Replications	1	132	132	0.1457	
Residuals	15	13500	899		

Table 3. Analysis of variance for capacity

Parameter	Df	Sum of Square	Mean Square	F-value	Pr(>F)
Operating speed	1	541554	541554	682.7825	2.4002e-15***
Feed rate	1	9020	9021	11.3803	0.002528**
Feed size	1	195	195	0.2455	0.626021
Speed: Feed rate	1	6443	6443	8.1267	0.01008
Residuals	19	15048	789		

Table 4. Analysis of variance for cutting length

Parameter	Df	Sum of Square	Mean Square	F-value	Pr(>F)
Operating speed	1	123.873	123.873	62.1742	1.472e07***
Feed rate	1	0.375	0.375	0.1886	0.66852
Speed: Feed rate	1	8.189	8.129	4.0582	
Residuals	20	39.972	1.988		

4 CONCLUSIONS

A corn shredder was designed, constructed and evaluated for shredding the left-over cornstalks with the goal of minimize wastage and drudgery in providing suitable pasture for optimum and profitable livestock production. Results obtained shows that the maximum mean shredding capacity of the shredder was 558.32 kg/h was attained when the shredder was fed by 6kg of corn stalks with an average thickness of 250mm at a speed of 2500 rpm. The study revealed that the interactions of these parameter were also significant on the capacity of the shredder but were not significant on the size of the feed stalks. It also indicated that the operational speed of the shredder was significant on the length of cut of the shredded corn stalks.

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