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Research Paper

Optimization of a Prototype Agricultural Waste Shredder.

Jimoh, R.O., Obiakor, S.C., Haruna, A.A., Willoughgy, F.A., Ojukwu, O.E., Ochin, N.G., Ojo, O.A. and Ehiosun, P.E .
National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria.

Abstract
Waste generation has become a major concern to the government and the environmental regulatory bodies, couple with the current population, economic and social pressures in Nigeria. The study is focused on the utilization of locally available materials for the development and optimization of a prototype Agricultural Waste Shredder. The shredder comprising of a feeding unit, shredding unit, power transmission unit and a machine frame. Performance analysis was carried out on the machine using a mixture of beans stalk, coconut husk, tree branches and woods as the agricultural waste test materials; the performance indices investigated were shredding efficiency and output capacity. Response surface methodology (RSM) was used to optimize the machine operational efficiency at various speeds levels of 360, 650, and 975 Rpm, and with sieve apertures of 20.00, 30.00, and 40.00mm respectively, An optimum shredding efficiency of 93% was obtained at a shredder aperture of 20mm and a shredding operational speed of 975rpm, also the maximum output capacity was 6.10kg kg/min at an operational speed of 975rpm, while a minimum output capacity of 5.14kg/min and a minimal shredding efficiency of 61% was obtained with a shredder aperture of 40mm at operational speed of 325rpm. A second order regression model was developed for shredding efficiency with an R^2 of 70.42% suggesting the fitness of the model. The machine is easy and economical to use, which is recommended for small and medium scale entrepreneurs in agriculture.

Keywords: *Optimization, Prototype, Shredding Machine, Agricultural Waste, Efficiency***.**

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I. INTRODUCTION

Agriculture is considered as a major occupation in many parts of the world, a large portion of Nigerians indulge in Agriculture at subsistence level, with a populations faced with issues arising from waste materials disposal resulting from pre and post agricultural activities, thus requiring a variety of technologies for the treatment and management of waste. It is estimated that wastes accounts for over 30% of worldwide agricultural productivity (Adewumi and Omoresho, 2002).

Agricultural waste, which is the non-product outputs of production and processing, often contains materials that can benefit man if reprocessed. Their composition depends on the nature and type of agricultural activities carried out; the waste can be natural (organic) or non- natural waste (Obi *et al*., 2016).

The conventional agro-waste disposal where agricultural wastes are dumped in a particular place to degrade and decompose, this process often results to environmental pollution. This makes it pertinent to adopt a more appropriate technology that would minimize the negative impact of agricultural waste on the environment by reprocessing or recycling it, making it eco-friendly and useful for man for agricultural purposes.

The waste shredding process is considered a very viable method which aims at reducing the agro waste, effectively reducing pollution and disease causing organisms by converting it to a useful form such as agricultural manure with vermin compost.

Shredding process is usually done by the use of a simple shredding machine which simply converts macro agriculture waste and food waste into small easily decomposable forms that could be used as organic manure. The micro sized waste decomposes faster than the macro size waste. This decomposed waste can be used to improve soil nutrients, thereby leading to an increase in agricultural yield, high quality crops and an enhanced soil quality (Vitali *et al*., 2013), (Agamuthu, 2000),(Salah and EL-Haggar, 2007) .

Hande *et al*., (2014) developed a Portable Organic waste chopping Machine, the waste products is been feed uniformly to the machine chopping chamber through the feeding unit. The machine is operated at a speed of 1440 rpm, and powered by a 2hp electric motor providing the required power to the chopping drum to cut/shred the waste to micro pieces by the effect of impact shear obtained from the shredding blades. The pieces are collected through the concave holes of the sieve of the machine.

Nithyananth *et al*., (2014) designed and fabricated a modified waste shredder machine. The modified shredder machine as a ploughing attachment linked to a tractor shaft, the power from the Tractor is transmitted to the machine assembly. The assembly consists of one fixed blade and five circular rotating blades. The organic matter /waste is fed in to the machine and shredded in shredding chamber in to micro pieces.

The shreddering machines listed in the literature above still has a lot to be desired in terms of efficiency and efficacy of the final product which is as a result of the absence of a sieve for micro size reduction after shredding. Hence the aim of this study is to develop and optimize a prototype electric powered Shredder, with an enclosed shredding and sieving mechanism, using low cost and available material, yet possessing high shredding capacity and efficiency rate.

II. MATERIALS AND METHODS

2.1. Design consideration

In the design of the prototype agricultural waste shredder the following were taken into consideration:-

i. *Availability of materials*: low cost materials of adequate strength and durability were sourced locally and used for the fabrication of the machine.

ii. *Physical and mechanical properties*: relevant geometric mean diameter of some selected waste products was considered for the design of the machine.

iii. *Machine capacity*: Basic considerations were given to the design of the size, speed and capacity of the agricultural waste shredder.

iv. *The Operational Factors:* High operational speed ranges were considered in order to achieve an efficient and effective process, which also made the machine easy to operate, while maintaining a high operational safety.

2.2. Description and Operation of the Prototype Agricultural Waste Shredder

The agricultural waste shredder consists of the following major component: hopper, shreddering chamber, machine frame, sieves, and a waste collector, which is powered by an electric motor.

The hopper is designed to be parallelogram in shape with a shortened rectangular based pyramid situated at the top of the machine chamber, the machine chamber houses the shredder shafts, and also serves as an inlet for feeding the waste product into the shredding machine. When fed with the material, its slides down from the hopper into the cutting chamber for shredding. The sieve which is located underneath the shredding chamber, allows the micro pieces of shredded waste materials of less than 20mm in length to pass through the sieve holes. The collector is situated at the bottom of the sieve collects the micro fragments of shredded materials and directs it's in to a container which discharges via an outlet.

2.3. Design Calculations

i. Determination of Volume of waste shredder Hopper

The volume of the shredder hopper, V_{sh} in m^3, was calculated according to the general mathematics formula for shapes using equation (1).

$$V_{sh} = 1/3\,(B \times H - b \times h) \qquad 1$$

Where:

B = the area of the rectangular base (large pyramid) in m^2,

H = the height of the larger pyramid (m), b = the area of the rectangular base (small truncated pyramid) in m^2, and h = the height of the small truncated pyramid (m).

ii. Power Requirement for the shreddering operation

The power requirement for the shreddering machine was calculated according to (Shigley, 2005) in equation (2).

$$P = F \times V \qquad 2$$

Where:

P = power (Nms^{-1}), F = shredding force (N), and V = Velocity (ms^{-1})

iii. *Belt design*

The total belt length, (m), was calculated using the expression given by Khurmi and Gupta (2012), respectively

$$L = \pi/2\,(D_1 + D_2) + 2C + (D_1+D_2)^2/\,4C \qquad 3$$

$$C = (D_1+D_2)/2 + 0.05 \qquad 4$$

L = Belt Length (m), C = Centre length between two pulleys, D_1 = Pitch diameter of the first pulley (m), and D_2 = Pitch diameter of the first pulley (m).

iv. Shaft design

The combine twisting moments and bending moments were used to determine the shaft diameter using the formula given by Khurmi and Gupta (2012).

$$Te = ((K_B \times M)^2 + (K_T \times T)^2)^{0.5} = \pi \times S_S \times d^3/16 \quad 5$$

Where,

Te = equivalent twisting moment (Nm),
M = resultant bending moment (Nm),
T = Torque transmitted by the gear shaft (Nm),
Ss = Allowable shear stress for steel = 310N/mm^2 as given by Khurmi and Gupta, (2012)
d = diameter of the shaft in mm
K_B = combined shock and fatigue factor applied to bending moment = 2.0 for minor shock
K_T = combined shock and fatigue factor applied to torsional moment =1.5 for minor shock

v. Factor of Safety

This ensures that machine does not collapse structurally under the action of loads. F_oS which is the factor of safety is related to the yield strength (Y_S) of the selected material and the working stress or maximum stress (W_S), it was calculated according to Khurmi and Gupta (2012) in equation (6).

$$FoS = Y_S / W_S \quad 6$$

vi. Design drawing.

The orthographic, isometric and exploded views of the prototype agricultural waste shredder were drawn using the AUTO-CAD 2020 software version 23.1. The AUTO CAD drawings are shown in Figures 1-3.

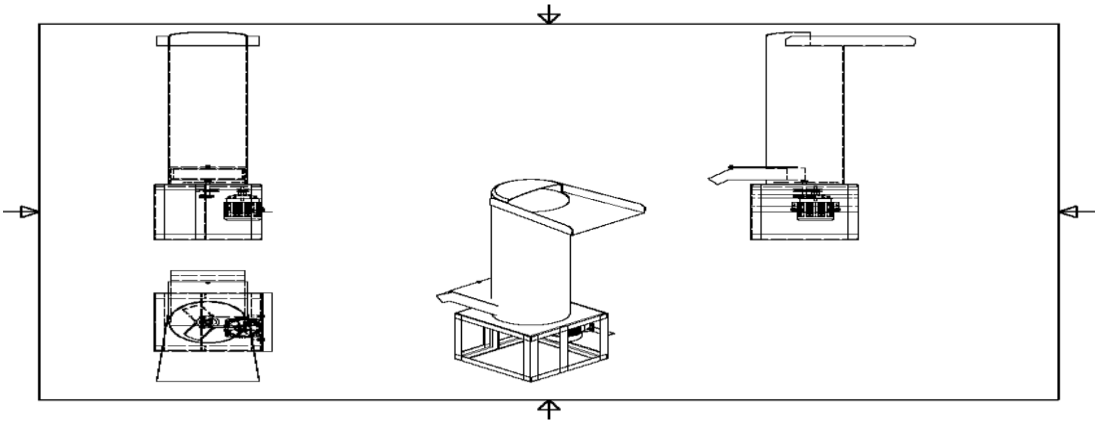


Fig.1: Autographic view of the prototype agricultural waste shreddering machine.

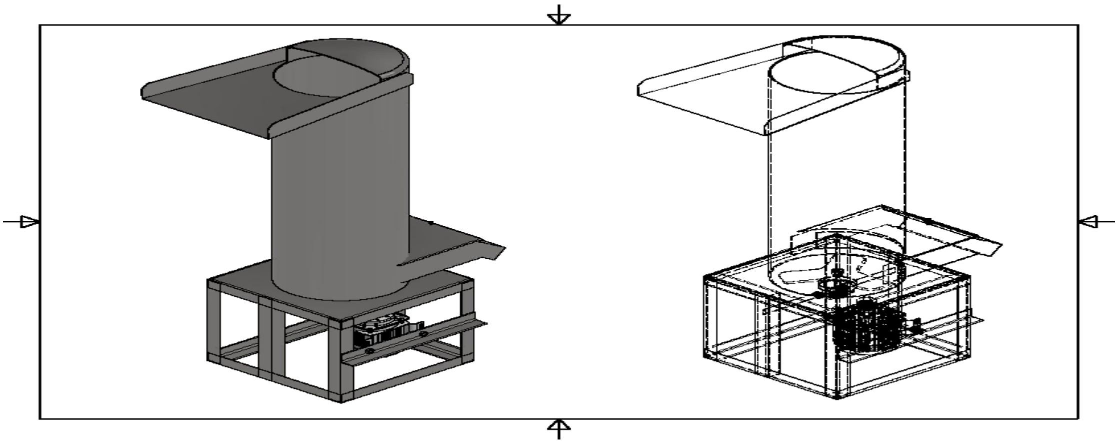
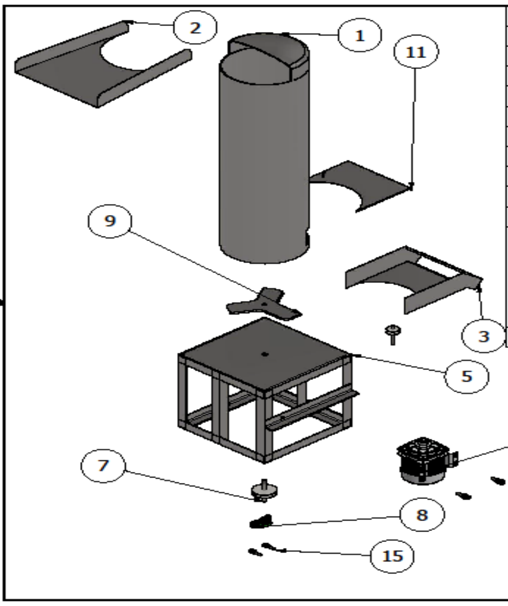


Fig.2: Isometric view of the prototype agricultural waste shreddering machine.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	cylinder	
2	1	hopper	
3	1	outlet shute	
4	1	base frame	
5	1	base plate	
6	1	electric motor	
7	1	shaft with pulley	
8	1	pillow bearing	
9	1	shredder blade	
10	2	ISO 4015 - M12 x 45	Hexagon head bolts - product grade B - Reduced shank (shank diameter ~ pitch diameter)
11	1	chute cover	

Fig.3: Exploded view of the prototype agricultural waste shredding machine.

2.4. Performance Analysis of the Prototype Agricultural Waste Shredder.

2.4.1. Test Methodology

The motorized agricultural waste shreddering machine, after the development of the machine, optimization analysis was carried out using a mixture of coconut husk, beans stalk, tree branches and woods as the agricultural waste test materials. The weight of the input, output and residue waste materials were measured and recorded in three (3) replicates using a weight measuring scale, the machine operational speed was measure using a digital tachometer and the time taken for all operations were recorded using a stop watch.

The agricultural waste mixture used was gotten from the local farm in Ilorin, Kwara state, was weighed and used for the performance analysis to evaluate the machine parameters.

2.4.2. Test Parameters

The test parameters helped to determine the effects of the machine parameters (the operational machine speed and the aperture sizes) on the machine performance and the quantity of the shredded materials, the formulas used for calculation were adopted according to Suryanto and Bardaie, (1996) and Olotu, (2012).

a. *shreddering Efficiency* (%): this determines how efficiently the shredder carries out the shredding of the waste. it is expressed in equation (7)

$$S_e = \frac{w_1}{w4} x100 \qquad (7)$$

Where w_4 = initial weight of the waste in kg and, w_1 = weight of the shredded waste in kg.

b. *Output Capacity* (Kg/hr): it determines the waste that is discharged from the outlet per unit time. it is expressed as

$$O_c = \frac{w1}{t_1} \qquad (8)$$

Where w_1 = weight of the shredded waste in kg and, t_1 = time taken for the operation in seconds.

2.4.3. Data Analysis

Response surface methodology (RSM) was used to develop a regression model between the independent variables (operational speed, and sieve apertures) and the dependent variable (shreddering efficiency). The model was optimized at various speeds levels of 360, 650, and 975 Rpm, with sieve apertures of 20.00, 30.00, and 40.00mm respectively. The test was subjected into triplicates during data collection.

III. RESULTS AND DISCUSSION

The shreddering operational speed is denoted as x_1 while the sieving aperture is denoted as x_2.

Tables 1,2 and 3 shows the performance parameters for the agricultural waste shredding machine at different operating speeds levels of 360, 650, and 975 Rpm, and with sieve apertures of 20.00, 30.00, and 40.00mm respectively. The P values in table 1 showed that the aperture sizes were more statistically significant compare to the speed variables, but the square of the speed shows a greater significant level.

The regression coefficient as displayed in table 1 shows that the coefficient for shredding speed is less significant having a p-value of 0.052. This concludes that all level means for speed are equal. The coefficient for a shredding aperture was significant at -5.167, having a p-value 0.000, and depicts that not all level means for speed is equal. Similarly, the coefficient for squared aperture showed no significant difference having 0.397 with a P-value of 0.607, This shows that the relationship between the aperture and the efficiency does not follow a curved line, while the relationship between the speed and the efficiency follow a curved line due to the fact that the coefficient for a squared speed showed a significant effect on efficiency having a value of 2.397 and a P-value 0.014.

Table 1: The Regression Coded Coefficient

Terms	Coef	SE Coef	T-Value	P-Value	VIF
Constant	82.172	0.508	161.63	0.000	
X_1	1.167	0.500	2.33	0.052	1.00
X_2	-5.167	0.500	-10.34	0.000	1.00
$X_1{*}X_1$	2.397	0.737	3.25	0.014	1.17
$X_2{*}X_2$	0.397	0.737	0.54	0.607	1.17
$X_2{*}X_2$	-0.500	0.612	-0.82	0.441	1.00

Table 2 summarized the model results, which explain 94.78% of the variation in shredding efficiency. However, the R^2 (pred) of 70.42% suggests that the model is fit. Models are often fitted with different predictors; however the adjusted R^2 values and the predicted R^2 values compare how well the models fit the data.

Table 2: Model Summary

S	R-sq	R-sq (adj)	R-sq (pre)
1.22441	94.78%	91.06%	70.42%

Table 3 shows the effects of Shredding speed and shredding aperture for both the linear, square, and interaction on the shredding efficiency. The result indicated that the effect of the speed on the efficiency of the machine was less significant compare to the aperture size.

This concludes that there is no statistically significant association between the efficiency and the speed of operating the shredder. The aperture diameter significantly had an effect on the efficiency having a p-value of 0.000. The square model for speed indicated a significant effect, which also concludes that there is a statistically significant association between the efficiency and the square of the speed, while the square of shredding aperture did not show any significant effect on the efficiency. The two-way interaction between the speed and aperture did not show any significant effect on the shredding efficiency as shown in table 3.

Table 3.Response Surface Regression efficiency versus speed and aperture of shredder

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	170.737	28.147	15.45	0.000
Linear	2	148.333	74.167	46.13	0.000
X_1	1	6.167	6.167	5.45	0.052
X_2	1	140.167	140.167	96.84	0.000
Square	2	11.403	9.702	7.14	0.020
$X_1{*}X_1$	1	8.863	8.863	10.58	0.014
$X_2{*}X_2$	1	0.443	0.443	0.29	0.607
2-Way interaction	1	1.000	1.000	0.67	0.441
$X_1{*}X_2$	1	1.000	1.000	0.67	0.441

$$\text{Efficiency (\%)} = 82.172 + 1.167x_1 - 5.167x_2 + 2.397x_1^2 + 0.397x_2^2 - 0.500\, x_1 x_2 \quad 9$$

The shredding efficiency of the agricultural waste shredder was maximum at the operating speed of 975 rpm and aperture size of 20mm with a value of *93*%. The sensitivity of the system suggests increasing the optimum speed by 1.167rpm with the square of 2.397rpm, and the aperture sensitivity by -5.167 mm with the square of 0.397mm will thus improves the optimum shredding efficiency. The optimization model equation for the shredding efficiency is given in Equation (9), and it indicates the importance of increased in the square of operational speed with a reduced aperture size for an effective and efficient shredding process

A regression equation was established for the processes and was optimized; results showed that the machine operation achieved an optimum efficiency of 93% and using optimum independent variables of speed 975rpm and an aperture size of 20mm.

From the analysis performed it is deducted that the aperture sizes during the sieving operation had more significant effect on the efficiency than the speed, though the speed had an effect, it was minimal. The result shows that the higher the speed of operation the higher the throughput capacity. At the speed of 975rpm, the machine was able to shred 6.10kg of agricultural materials, while at the lowest speed of 325rpm the total shredded material was 5.12kg, this agrees with the result of (Ayo et al., 2017). However the machine would therefore eliminate the constraints involved in the manual/conventional method of agricultural waste management and reduced the hazard/pollution associated to the process.

IV. CONCLUSION

An agricultural waste shredding machine was developed using locally available materials, Results from the analysis showed that the shredding aperture played a more significant role on the shredding efficiency of the machine. The shredding efficiency of the machine decreased with increasing shredding aperture but increases with shredding speed. Maximum shredding efficiency of 93% was achieved when the shredder aperture was 20mm at an operational shredding speed of 975rpm. The output capacity of the machine increased with the speed of shredding with a maximum value of 6.10kg kg/min at 975rpm and a minimum value of 5.14kg/min at 325rpm.

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