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Modification, Fabrication, and Performance Evaluation of Maize Threshing and Grinding Machine

Ugwu Kenneth Chikwado[1], Diyoke Chidiebere[2]
[1](Department of Agricultural &Bioresource Engineering, Enugu State University of Science and Technology, Enugu, Nigeria)
[2](Department of Mechanical/ Production Engineering, Enugu State University of Science and Technology, Enugu, Nigeria)

ABSTRACT

The threshing and grinding machine were modified, and their performance was evaluated. The modifications include reducing the device's height, changing the hopper, lowering the clearance of the threshing and grinding chamber, changing auger spacing, and changing the milling chamber to bur plate. The modified machine consists of threshing and grinding chambers. The maize grains were separated from the cob at the threshing chamber. Then the cob was collected through the outlet chute. The incorporated blower separates the maize grain from the chaff before entering the grinding chamber. The separated grain entered the grinding chamber and was grounded by compressive means through the plate. A 2 hp electric motor provides drive through belt connections to drive the pulley on the threshing chamber, and another 2 hp electric motor provides the drive for the grinding chamber. The actual test was conducted using three different moisture contents and feed rates. The efficiency of the modified machine was 86.14 % against 61.05 % of the old on the moisture content of 10 %. The analysis of variance (ANOVA) of the results obtained at a 5 % percent probability confirmed that the moisture content of the maize was an important parameter that affects the performance of the machine.

Keywords: *Modification, Performance Evaluation, Maize, Threshing, Grinding, Machine*

Nomenclature

w = weight (N)
δ = coefficient that depends on the angle of inclination
α = angle of repose (^{0})
θ = spiral angle on the auger (^{0})
F = force of friction (N)
d_0 = diameter of screw auger shaft (mm)
μ = coefficient of friction
ρ = density of material (kg/m^3)
R_N = normal reaction (N)
k = degree of filling the material
a_o = constant
v = velocity (m/s)
n = shape factor
s = stroke of auger (mm)
b = constant
p_s = screw auger pitch (mm)
M = moisture content (%)
D = diameter of screw auger (mm)
D_{av} = average particle diameter (mm)
Q = material capacity (kg/s)
c = constant
L = auger length (mm)
s_o = specific surface
C_s = capacity of screw auger (m^3/min)
d_o = constant
F_m = material factor in auger
V = volume (m^3)
π = constant, 3.142
h = height (mm)
δ_{sy} = Allowable shear stress (MN/m^2)
a = acceleration due to gravity (m/s^2)
M_t = Resultant torsional moment (Nm)
r = radius (mm)
M_b = Resultant bending moment (Nm)
m = mass (kg)
a_1 = length of trapezium at the top (mm)
P = power (kW)
b_1 = width of trapezium at the top (mm)
N = angular speed (rps)
a_2 = length of trapezium at the bottom (mm)
T = torque (Nm)
b_2 = width of trapezium at the bottom (mm)
d = diameter (mm)
K_b = bending moment's combined shock and fatigue factor
K_t = torsional moment's combined shock and fatigue factor

I. INTRODUCTION

Maize is the most crucial cereal grain globally, which provides nutrients for humans and animals and serves as a primary raw material for the production of starch, oil, protein, alcoholic beverages, food sweeteners, and more recently, fuel [8]. Maize is a staple food crop that is known even to the most impoverished family in Nigeria and beyond. It is served in many ways as food to alleviate hunger, and such forms include maize flour, pap, or ogi. It is because of the importance of maize that it is processing and preservation to the normal condition must be analyzed; the steps involved in the processing of maize are harvesting, drying, de-husking, storing, threshing, and grinding, for the local farmers to maximize profit from the maize production, adequate technology that suits their needs must be used. One of the essential processing operations done to raise the quality of maize is threshing and grinding [2]. The maize plant is a tall, determined, monoecious, annual plant. It developed large, narrow, opposite leaves, borne alternatively along the length of the stem. The maize species follow the same general pattern of development, although specific time and the interval between stages and the total number of leaves produced may vary between different hybrids, seasons, time of planting, and location [3].

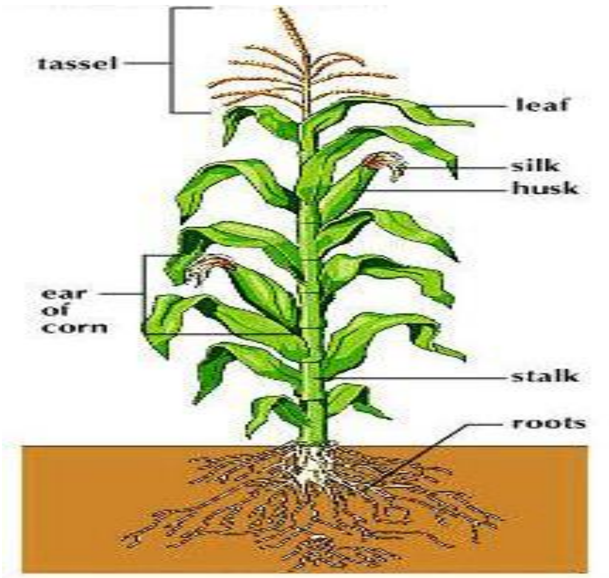


Fig 1: Parts of a fully matured maize plant [14]

Post-harvest operation of maize grains on-farm can help producers and farm managers control elevator discounts and increase economic returns to their operation [4]. Treatment of maize soon after harvest often determines a crop's storability and can strongly influence its quality when delivered to the end-user, which may be several weeks, months, or even years after harvest. Therefore, it depends on maize farmers to implement sound maize harvest, handling, and storage practices to maintain good quality maize to the global market. Successful post-harvest grain processing with on-farm facilities requires a thorough understanding of the factors that influence grain quality [6].

Maize threshing machines are varied, including the handheld thresher, small rotary hand thresher, and free-standing manually operated thresher. The different ways of maize grinding can be based on various mechanization technology used. These include: manually operated and electric motor driving. Manually operated involves using the hand in operating the maize grinding machine, while electric motor driving involves the use of a motor for running the engine. The electric motor technology involves the use of mechanical assistance in grinding the maize [14]. The engineering properties of maize are useful in maize farming, harvesting, and storage or in processing such as drying, threshing, milling, and others. This knowledge is essential in the designing and construction of maize thresher, grinder, and also in the preparation of the processing chain from grain to food. The accurate design of machines and processes in the food chain from harvest to table requires an understanding of the physical properties of raw material [1].

The maize grain gives the highest conversion ratio to meat, milk, and eggs compared with other grains used as livestock feed. This is due to its high starch and low fiber content, making it a very concentrated source of energy for livestock production. There are no available statistics for maize and livestock use; it is believed that a more significant portion is used as poultry feed in tropical countries. Yellow maize is preferred for livestock feed, and it is used as whole grains, cracked or coarse ground, dry or wet or steamed, and generally supplemented with vitamins and other proteins [13]. Traditional threshing and grinding methods do not support large-scale processing of maize, especially for commercial purposes. The region that produces the highest quantity of maize locally in Nigeria is the northern part of the country, and it was observed that most threshing of the produced maize was done by hand threshing. Hand threshing takes much time, even with some simple hand-operated tools. It was also observed that most mechanical threshers were designed for multi-grain threshing, which causes significant damage to the maize seeds besides breaking the cob to pieces. The available threshers locally were equipped with rotating threshing drums with beaters or teeth, which cause damages to the seed. The cost of purchasing such threshers was high for the rural farmer, and therefore necessitated the modification of a low-cost system that will be affordable and increase threshing and grinding efficiency but reduce the damage done to the seed [14].

The multipurpose processing machine reduces the workload of moving the materials from one location to the other. The main objectives of this project are to modify and construct a maize threshing and grinding machine and to evaluate its performance.

II.MATERIALS AND METHODS

A motorized vertical maize threshing and grinding machine, which is efficient and economically viable, was modified and fabricated with available and cheap materials (suitable engineering materials that could give optimum service performance). The materials used in fabricating the machine were chosen based on their availability, suitability, economic consideration, viability in service. [14]. The components parts of the machine were modified, fabricated, and evaluated. The parts and their quantity are given in the part list below.

A. height of the machine

The height of the machine was chosen based on the average height of the human being that operates it. The anthropometric data of the assumed operators were measured, and the average height was used to design the machine.

B. Design of Hopper

The hopper has the shape of a trapezium. The angle of repose and volume of the hopper was determined using equation1, 2, and 3 below; A body will only begin to move down the when

$$w\sin\alpha = F = \mu R_N = \mu w\cos\alpha \quad [10] \qquad 1$$

If the material is dependent on moisture content, the angle of repose will be determined by

$$\tan\alpha = a_0 n^2 + b\left(\frac{M}{D_{av}}\right) + cs_0 + d_0 \quad [7] \qquad 2$$

The volume of the trapezium hopper was determined by

$$V = \{(a_1 b_{1+} a_2 b_2) + (a_1 b_{1+} a_2 b_2)/2\}h/3 \quad [12] \qquad 3$$

C. Design of Threshing and Grinding Casing

The threshing and grinding casing were assumed cylindrical; the volume of the cylinders was determined using equation 4

$$V = \pi r^2 h \quad [12] \qquad 4$$

D. Selection of Electric Motors for Threshing and Grinding

The forces each required to thresh and grind maize were determined using equation 5. The powers required to produce these forces were computed using equation 6

$$F = ma \quad [9] \qquad 5$$

$$P = \frac{2\pi NT}{60} \quad [9] \qquad 6$$

E. Shafts design consideration.

The shaft is a cylindrical solid rod for transmitting motion through a set of the load carried on it. The shaft uses for the threshing is loaded by a perforated drum, bearings, pulley, and belt tension. All these forces act on the shaft. The operation is based on fluctuating torque, bending moment, and shearing force [14]. These called for knowing the combined shock and fatigue on the shaft. To determine the shaft diameters for threshing and grinding, we adopt the formula;

$$d^3 = \frac{16}{\pi\delta_{sy}}[(K_b M_b)^2 + (K_t M_t)^2]^{\frac{1}{2}} \quad [9] \qquad 7$$

F. Screw Auger Design

Screw auger is a vertical rotating shaft twisted of a plate of mild steel housed by the threshing casing. The power required to drive a screw auger and convey materials depend on the characteristics of the material handled and the length of the auger. For normal condition, the power input to the auger shaft is approximately computed using the formula below

$$P = \frac{C_s LWF_m}{33{,}000} \quad [5] \qquad 8$$

From the capacity of materials handled by the machine, the screw auger diameter was determined by

$$Q = \frac{\pi\{D^2 - d_0^2\}SVK\rho\delta}{4} \quad [11] \qquad 9$$

The axial pitch of the screw auger for threshing was calculated using equation 10

$$\tan\theta = \frac{\pi D}{p_s} \quad [11] \qquad 10$$

G. Selection of grinding plate

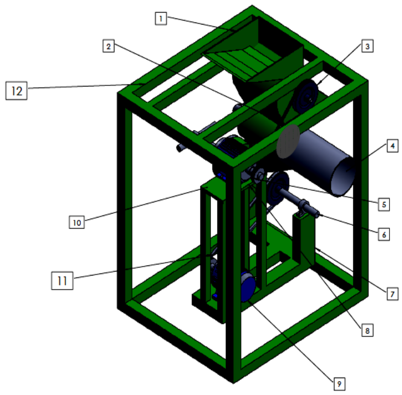
Four different grinding plates fall within the speed limit of the grinding machine. A233 is for medium fine for small grains, A434 is for medium fine for small grains of high capacity, B41 is for uniform coarse for small grains, and B43 is for extremely fine for small dry grains. Based on the description above, B43 was selected for the particular grinding process [7].

H. Principle of Operation of the machine

The threshing and grinding machines have two chambers. These are the threshing unit and grinding unit. An electric motor of 2 hp provides drive through belt connections to drive the pulley on the threshing unit, and another electric motor of the same power provides the drive for the grinding unit. The maize's cobs were introduced to the machine through the hopper and were received by the first unit. The threshing was done with the perforated drum's help, and the blower, which was incorporated close to the threshing chamber, separates the chaff from the corn. The whole corn enters into the second unit for grinding through stationary and moving plates against each other.

I. Modification of the machine

The height of the machine was reduced from 520 mm to 473 mm to accommodate everybody in the operation of the machine. The reduction was to eliminate the stress and fatigue to be incurred in stretching or bending loading the materials into the hopper. A well-designed hopper was incorporated to avoid clogging of material during loading and prevent either splashing or flying back of materials from the hopper. It also contributed to the high efficiency of the machine. The large clearance between the mechanism and the casing in both the threshing and grinding chamber was lowered to increase the machine's efficiency. The auger for threshing was redesigned, and suitable bur pates were chosen for higher performance.



NO	NAME
1	HOPPER
2	BELT 1
3	PULLEY
4	CHAFF OUTLET
5	ELECTRIC MOTOR
6	GRINDING SHAFT
7	CARRIAGE
8	ELECTRIC MOTOR 1 SEATING
9	ELECTRIC MOTOR 2
10	ELECTRIC MOTOR2 SEATING
11	BELT 2
12	FRAME

Fig 2: Isometric Drawing of the machine

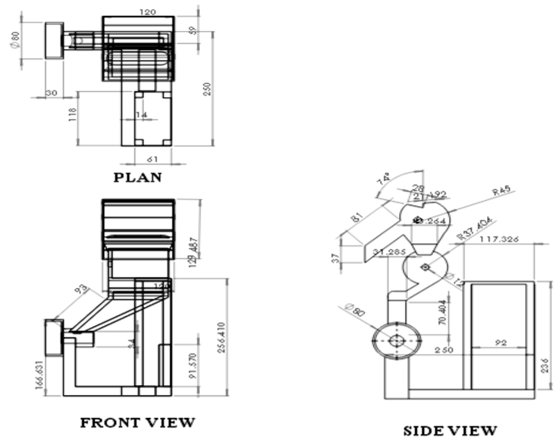


Fig 3: Orthographic view of the machine

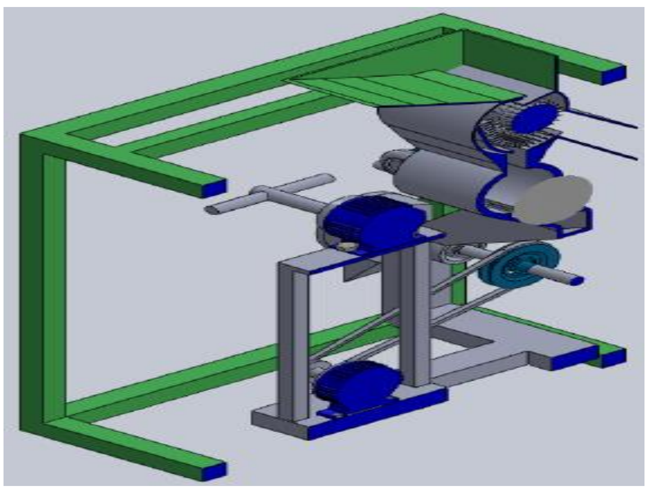


Fig 4: Section drawing of the machine

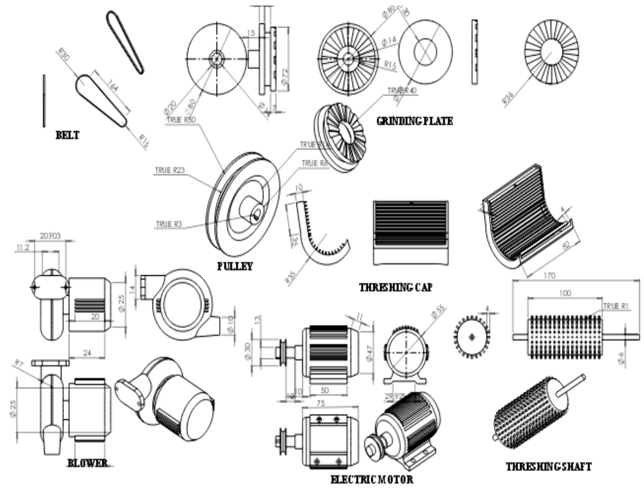


Fig 5: Part drawing of the machine

J. Evaluation of the machine

The machine was run freely without load using the selected electric motor at both units to get the smoothness of operation of the rotating machine parts. The usual test was done using three different moisture contents and feed rates of maize cobs. Evaluation of the machine was targeted at comparing its threshing and grinding efficiency, throughput capacity, and percentage recovery rate with the existing machine. The results obtained were analyzed using analysis of variance (ANOVA).

III. RESULTS AND DISCUSSION

The machine efficiency was determined using three different moisture contents: 10%, 15%, and 20% at three different feed rates of 65kg, 85kg, and 105kg of maize cobs. The performance evaluation carried out was to determine the machine threshing and grinding efficiency, the throughput capacity, and the percentage recovery rate at a fixed time of 67 seconds. The results gathered were compared with the existing results. From the results presented in table 1, it was seen that the efficiency of the modified machine increases at a reduced moisture content. The average highest efficiency of the machine was 83.97 % at 10% moisture content, and the lowest at75.85 % on 20% moisture content. It was also discovered that the average recovery rate of the milled maize was highest at 31.93 kg on 10% moisture content and lowest at31.38 kg on 20% moisture content. The results obtained from the machine using 85 kg of maize as feed rate at 10%, 15%, and 20% of moisture contents were shown in table 2. The average highest efficiency of the machine was 86.14 % on 10% moisture content, and the lowest was 76.98 % on 20% moisture content. The results also showed that the average recovery rate of the milled maize was highest at54.71 kg on 10% moisture content and lowest at47.21kg on 20% moisture content. The results obtained at the 105kg feed rate of maize on three different moisture contents were shown in table 3. It was also seen that the average highest efficiency of the machine was 85.63 % on 10% moisture content, and the lowest was 76.27 % on 20% moisture content. The average recovery rate of the milled maize was highest at64.72 kg on 10% moisture content and lowest at 62.00 kg on15 % and 20% moisture content, respectively. Table 4 showed the analysis of variance (ANOVA) of the results obtained at 5% percent probability, which signified that the moisture content of the maize was an important parameter that affects the performance of the machine. Feed Rate does not affect the performance of the machine significantly, according to the analysis.

Table 1: Machine performance on 65 kg feed rate at three different Moisture Contents

Moisture Contents (%)	Weight of maize introduced (kilograms)	Weight of cobs received (kilograms)	Weight of maize ground (kilograms)	Weight of chaff (kilograms)	% variation	Machine efficiency (%)	Time of operation (Seconds
10	65	28.54	30.62	1.41	1.42	82.82	67
	65	30.26	31.80	1.84	3.63	84.55	67
	65	28.53	31.52	1.04	1.33	82.75	67
	65	27.97	33.24	1.56	1.17	84.10	67
	65	30.11	32.48	2.40	1.50	85.62	67
	Average	**29.08**	**31.93**	**1.65**	**1.81**	**83.97**	**67**
15	65	31.70	31.48	2.27	0.25	81.67	67
	65	28.62	30.55	2.32	3.10	80.76	67
	65	29.52	32.49	2.38	3.94	81.32	67
	65	30.18	31.20	2.32	2.51	81.48	67
	65	29.68	32.16	1.16	2.46	81.15	67
	Average	**29.95**	**31.57**	**2.09**	**2.45**	**81.28**	**67**
20	65	31.30	31.09	2.96	4.18	78.05	67
	65	30.13	31.98	1.35	2.45	75.20	67
	65	30.72	30.40	2.02	4.25	74.36	67
	65	31.62	30.86	1.86	2.90	75.79	67
	65	29.56	32.56	1.63	1.38	75.84	67
	Average	**30.67**	**31.38**	**1.97**	**3.03**	**75.85**	**67**

Table 2: Machine performance on 85 kg feed rate at three different Moisture Contents

Moisture Contents (%)	Weight of maize introduced (kilograms)	Weight of cobs received (kilograms)	Weight of maize ground (kilograms)	Weight of chaff (kilograms)	% variation	Machine efficiency (%)	Time of operation (Seconds
10	85	27.95	48.43	2.71	0.73	86.27	67
	85	26.23	53.91	1.71	0.28	86.72	67
	85	21.93	56.34	1.10	0.71	86.29	67
	85	25.34	55.11	1.05	1.06	85.94	67
	85	19.24	59.73	1.45	1.51	85.49	67
	Average	**24.14**	**54.71**	**1.61**	**0.84**	**86.14**	**67**
15	85	25.20	54.33	1.94	1.24	79.68	67
	85	23.59	55.97	1.57	1.59	81.79	67
	85	32.00	49.00	1.09	0.59	80.29	67
	85	28.90	50.43	1.81	1.58	81.40	67
	85	24.46	54.71	1.94	1.61	80.67	67
	Average	**26.83**	**52.89**	**1.67**	**1.32**	**80.78**	**67**
20	85	37.09	42.15	3.45	2.97	77.06	67
	85	27.41	53.27	1.70	0.86	76.71	67
	85	27.94	52.92	2.14	2.36	77.71	67
	85	35.88	44.68	1.01	1.25	76.72	67
	85	36.80	42.97	1.78	1.98	76.69	67
	Average	**33.03**	**47.21**	**2.02**	**1.89**	**76.98**	**67**

Table 3: Machine performance on 105 kg feed rate at three different Moisture Contents

Moisture Contents (%)	Weight of maize introduced (kilograms)	Weight of cobs received (kilograms)	Weight of maize ground (kilograms)	Weight of chaff (kilograms)	% variation	Machine efficiency (%)	Time of operation (Seconds
10	105	27.57	70.04	1.71	1.45	85.55	67
	105	28.63	67.80	0.97	1.17	85.83	67
	105	35.86	62.41	2.20	1.25	85.75	67
	105	33.90	60.40	2.37	0.84	86.16	67
	105	32.94	62.93	2.02	2.11	84.89	67
	Average	**31.78**	**64.72**	**1.85**	**1.37**	**85.63**	**67**
15	105	28.22	66.96	1.60	2.84	81.87	67
	105	37.89	57.72	2.14	2.00	81.49	67
	105	37.61	56.65	2.32	3.01	81.90	67
	105	31.71	64.66	1.86	1.58	79.59	67
	105	33.89	64.00	1.33	0.72	80.10	67
	Average	**33.86**	**62.00**	**1.85**	**2.03**	**80.98**	**67**
20	105	34.91	61.75	1.49	0.84	75.46	67
	105	39.45	58.49	2.29	1.16	76.30	67
	105	34.84	61.56	0.91	0.75	75.29	67
	105	33.43	63.28	2.23	3.06	76.72	67
	105	30.63	64.96	1.25	2.55	77.58	67
	Average	**34.65**	**62.00**	**1.64**	**1.67**	**76.27**	**67**

Table 4: ANOVA for the effect of moisture content and feed rate on the machine performance

Variate: EFFICIENCY_%

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr**
FEED_RATE_kg	2	6.7201	3.3601	4.41	0.019
M_C_%	2	592.0045	296.0022	388.55	<.001
FEED_RATE_kg.M_C_%	4	10.2116	2.5529	3.35	0.020
Residual	36	27.4253	0.7618		
Total	44	636.3615			

IV. CONCLUSION AND RECOMMENDATION

The machine for threshing and grinding maize was modified, fabricated, and evaluated. The results showed that the machine performed well at low moisture content. The highest average efficiency of the machine was 86.14 % on 10% moisture content using 85kg of maize as feed rate, and the lowest average efficiency was 75.75 % on 20% moisture content using 105kg of maize as feed rate. It was discovered that moisture content affects the performance of the modified machine. The recovery rate of the milled maize was highest on 10% moisture content and lowest on 20% moisture content. The feed rates used to test the modified machine do not show a significant variation in machine efficiency. The efficiency of the modified machine was 86.14 % against 61.05 % of the existing machine on the moisture content of 10 %. The double operation of threshing and grinding of maize at the same time reduced the labor cost and time involved in the processing of maize. The machine is recommended to the farmers and other maize processors because of its time limitation, ease of operation, and good quality of milled maize. For hygienic, better purposes, and better quality of milled maize, stainless steel material is recommended for the construction.

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