DEVELOPMENT OF MAIZE DEHUSKING AND SHELLING MACHINE WITH A BLOWING UNIT

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ABSTRACT
Maize dehusking and shelling is traditionally done by first tearing off the husk from the cobs and subsequently rubbing cobs against each other, rubbing each cob against bricks or using wire meshes. These methods are strenuous, time consuming and result to high level of wastage. In this research, a mechanically operated maize dehusking and shelling machine with a blowing facility of low cost and high efficiency was developed. Three speeds were chosen to evaluate the performance of the developed machine. Effect of varying machine speed (576, 700 and 800 rpm) on the shelling efficiency of the machine and the corresponding effect on the blowing efficiency was evaluated at three different loading capacity (5, 7 and 10 kg). The machine efficiency was calculated for different machine speed and loading capacity in evaluating the shelling efficiency, cleaning efficiency, throughput capacity and percentage whole grain. It was observed that for mechanically operated maize dehusking and shelling process at a moisture content of 14 % wet basis and machine rotating speed of 700 rpm, the shelling efficiency was 99.89 % at 10 kg hopper loading. Maximum whole grain recovery with minimum loss of grains was observed as 87.99 % at machine speed of 800 rpm at 10 kg hopper loading. The cleaning efficiency of the machine was observed as 92.81 % at machine speed of 800 rpm and loading capacity of 10 kg.

Keywords: *Maize, shelling, husking, performance evaluation, blower, efficiency.*

1.0 INTRODUCTION

Farm operations such as harvesting, threshing and post-harvest operations require mechanization and demand the use of suitable and appropriate equipment to obtain higher operational efficiencies at optimum rate (Hussain, 2009). Normally cobs are plucked from the standing maize crop and thereafter the maize stalk is harvested. After plucking the maize cob, it is dehusked manually and then dried in the sunshine to reduce moisture content to 15-21% dry basis (d.b) for shelling to get the grain from the cob. The activity related to removal of the outer sheath from the plucked cob (called dehusking) is mostly performed by farm women. It is also observed that except beating with a stick, removal of grain from rest method (finger, sickle, etc.) is done by farm women (Singh, 2010). Shelling or threshing is the removal of maize grain from the cob, winnowing and cleaning which involves separating the chaff and broken cobs from the grain. More efficient shelling is achieved when the grain has 14% moisture content. This local way of separating seeds from straw was hard, dirty, inefficient, uneconomical, time consuming and slow at a time when agriculture was undergoing rapid technological advancement in most developed countries (Kareem 2011). The problems associated with old method of maize dehusking and shelling are little output, cumbersome, material wastage, time consuming, poor hygiene, cost and energy consuming.

Therefore, there is a need to develop a multi-functional machine that can perform the dehusking, shelling and blowing in one unit locally for an average farmer to be able to afford it and significantly reduce the stress of de-husking; time used in threshing; overall cost of post-harvest production; and the damage done to maize seeds during threshing. The objective of this work is to develop and evaluate maize dehusking and shelling machine with blowing unit.

2.0 METHODOLOGY

A. Design Considerations

The following design factors were taken into consideration, durability, strength, corrosiveness, availability and size. The design of the machine barrel to ensure maximum conveyance, dehusking, and shelling of the maize cobs without causing damage to the grains was also taken into consideration. The consideration was carried out for adequate and efficient dehusking and shelling.

B. Machine component design calculation

Table 1: Parameters of other functioning parts of the Machine

S/N	Parameter calculated	Value of parameter
1	Volume of hopper (V_h)	12.6 m^3
2	Angular velocity (ω)	150.82 rad/sec
3	Driving Pulley Diameter (D_C)	100 mm
4	Driven Pulley Diameter (shelling shaft) (D_B)	300 mm
5	Driven Pulley Diameter (blowing shaft) (D_A)	120 mm
6	Shape of belt	V belt
7	Type of belt	A
8	Belt Speed (V)	67.87 m/s
9	Tangential Load per arm at main shaft pulley (W_{Tmsp})	221 N/m
10	Length of Belt (L)	2.7 m
11	Compressive stress induced in the main shaft (σ_t)	589.6 kN/m^2
12	Angle of Lap (γ)	161°
13	Shaft Diameter (D)	25 mm

14	Belt Tension (T_1; T_2)	6.0 N; 19.54 N
15	Load on Shaft (T_w)	50.04 N
16	Drive Shaft Torque (T_{mp})	26.53 N
17	Driven shaft Torque (T_{msp})	66.31 N
18	Power Required to drive the shaft (P)	1.8 kW (5.5 hp)

i. Volume of hopper

The hopper has the shape of a frustum of a pyramid truncated at the top, with top and bottom having rectangular forms as shown in Figure 1. The volume of the hopper is a function of the dimension of the maize which also depends on the volume of the maize to be fed into the shelling cage per batch.

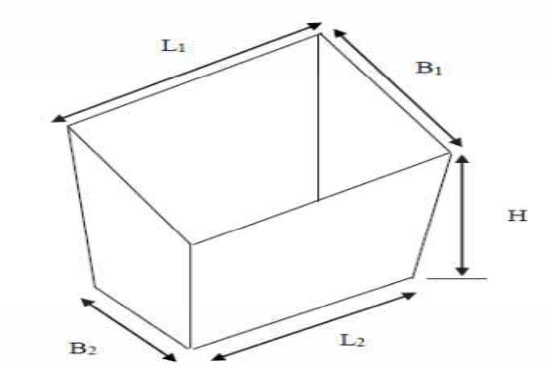

Figure 1: Isometric view of the hopper

Volume of hopper according to Masser and Jensen (1991); and Eric *et al*., (1982) is;

$$V_h = {}^{h}/_{3}\left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right) \quad (1)$$

where; V_h = Volume of hopper, A_1 = Hopper inlet area, L_1 = Length of outlet point, B_1 = Breadth of outlet point, A_2 = Hopper outlet area, L_2 = Length of inlet point; B_2 = Breadth of inlet point, H = vertical height of hopper

$A_1 = 63.8\ m^2$, $A_2 = 22.47\ m^2$, H = 0.305 m

$$V_h = {}^{0.305}/_{3}\left(63.8 + 22.47 + \sqrt{63.8 \times 22.47}\right)$$

$V_h = 12.6\ m^3$

The calculated capacity of $12.6\ m^3$ will allow the operator to feed the machine as many times as possible. This prevents overloading or any form of clogging when the machine is in operation.

ii. Shelling cage

The shelling cage comprises of a shaft carrying the shelling cage with the spikes and the beaters positioned on the shelling drum, with two pillow bearing at both ends. The diameter of the shelling cage determines the diameter of the shaft. The diameter of the cage is a function of the average length and breadth of dry maize. Figure 2 shows the side view of the shelling cage.

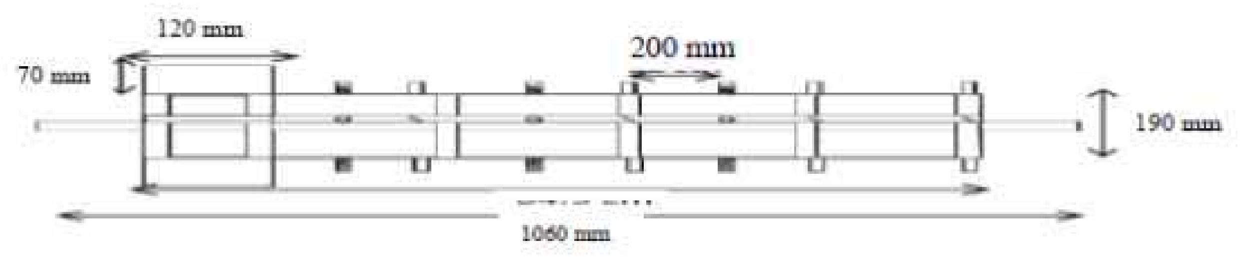

Figure 2: Side view of the shelling cage.

The diameter of the shelling cage as suggested by Eric *et al*., (1987)

$$d_c = d + 2H_s + 2M_w + 2C \quad (2)$$

where: d is the diameter of the shelling cage shaft, = 0.025 m; H_s is the height of the spike, = 0.058 m; W_m is the maximum width of the maize cob with grain, = 0.2 m and C is the smallest diameter of grain (clearance) = 0.0041 m

Therefore:

$d_c = 0.025 + 2(0.058) + 2(0.2) + 2(0.0041) = 0.6022$ m

iii. Design of spikes (beaters and Spikes) on the shelling cylinder

The design of the spikes on the shelling cylinder was carried out using Equation 3 according to Khurmi and Gupta, (2008)

$$N_p = \frac{L_c}{SS_c} \times \frac{\pi_c}{SS_t} \quad (3)$$

Where: L_c is the length of the shelling cylinder, SS_t is the spike spacing in the row, SS_c is the spike spacing on the circle, d_c is the diameter of the shelling cylinder.

$$N_p = \frac{845}{300} \times \frac{3.142 \times 602.2}{200}$$

$N_p = 27.2$

Therefore, N_p was taken as 28.

The maximum numbers of spikes and beaters that will dehusk and shell the maize if 28 at it must be evenly distributed on the shelling cage for efficiency.

iv. Shaft design

Loads acting on the shafts are metal rings, flat bars, spikes, beaters, pulley and metal plates. Dimensions of components on the shafts was based on the shape and size of the shelling cage and the clearance from the shaft to the shelling cage.

Spikes

The number of spikes is a function of the maximum volume of the maize in the shelling cage during operation. Length of spike is chosen based on the distance between the shelling drum and the shelling cage casing and the clearance.

Determination of weight of spikes (W_s)

Total mass of spikes = 6.275 N

Beaters

The function of the beater is to complete the shelling processes by beating the maize and removing it from the cob. Its function is similar to that of the spikes with additional function of conveying the cob and husk to the paddle section of the shelling drum.

Determination of weight of beaters (W_b)

Total weight of beater = 9.2416 N

Flat bar

The function of the flat bar is to hold the circular rings forming the shelling drum together and also carry the spikes and beaters.

Determination of weight of flat bar (W_{fb})

Total weight of flat bar = 7.208 N

Circular Plate

Determination of weight of circular plate (W_{cp})

Total weight of circular plate = 6.552 N

Circular Rings

Determination of weight of rings (W_r)

Total weight of rings = 1.148 N

Determination of weight of pulley on shaft

Mass of pulley was determined using spring balance as 7.64 kg

Weight = 74.85 N

Total weight on Shaft

$$\boldsymbol{T_s = W_s + W_b + W_{fb} + W_{cp} + W_r + W_f} \quad (4)$$

T_w = 6.275 + 9.2416 + 7.208 + 6.552 + 1.148 + 19.62 = 50.04 N

v. Shaft design

The purpose for the design of shaft is to ensure the appropriate strength and rigidity required to transmit an applied torque is ensured. The strength in torsion of shafts made of ductile materials are usually calculated on the basis of the maximum share theory. The shear force diagram of the shaft is represented in Figure 3.

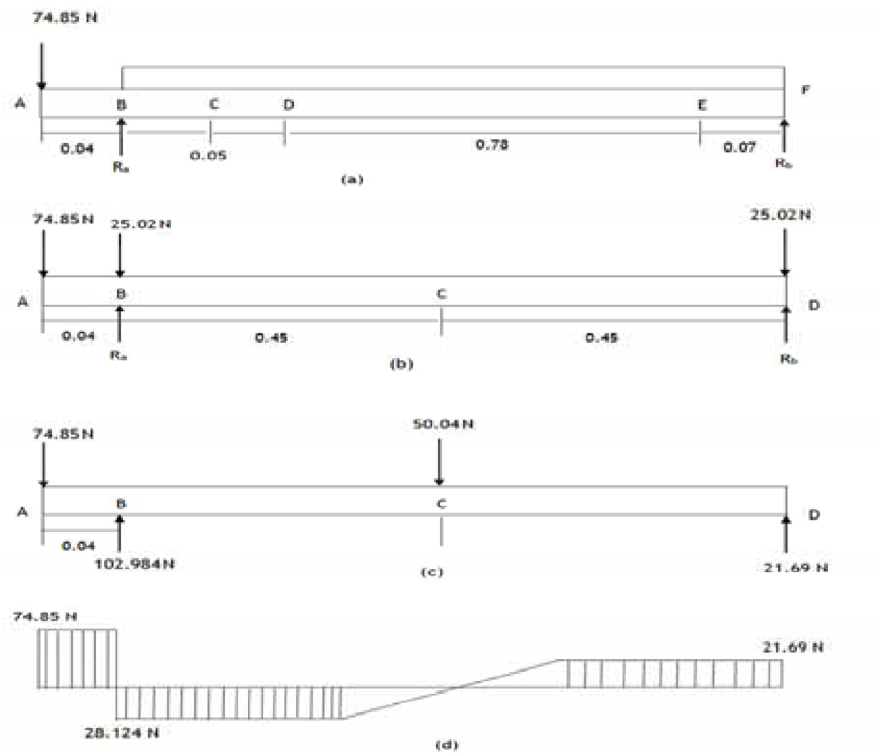

Figure 3: Shear force diagram of the shaft

vi. Determination of power required to drive the pulley and shaft

Weight of pulley = 74.85 N, Radius of pulley, r = 0.15 m, Speed of electric motor in minutes = 1440 rev/min

Speed of electric motor in Seconds, n = 1440/60 = 24 rev/sec

Angular velocity (ω) = 2πn (5)

= 150.816 rad/sec

Power required = weight × linear velocity

= 1.69 kW

Total power required = 1.7 kW

1.7 kW = 5.15 hp

Electric motor of 5.5 hp is selected

vii. Determination of Shaft diameter

For a solid shaft made from ductile material having little or no axial loading, the shaft diameter is obtained from ASME code equation according to Khurmi and Gupta, (2008).

$$\boldsymbol{d^3 = \left(\frac{16}{\pi S_s}\right)\sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \quad (6)$$

where

$$\boldsymbol{M_t = \frac{power}{2\pi n}}$$

= 2.6 Nm

Shaft torsional shear stress, Ss

$$Ss = \frac{T \times R}{J} \tag{7}$$

Where J is the polar moment of area

$$J = \frac{\pi D^4}{32} \tag{8}$$

Where;

D = shaft outside diameter; d = inside diameter, Kb = combined shock and fatigue bending factor,

Kt = combined shock and torsional factor, Ss = Allowable stress.

From Equation 6,

$$d^3 = \frac{16}{3.142 \times 55.11 \times 10^6}\sqrt{(1.5 \times 2.99)^2 + (1.0 \times 2.6)^2}$$

$d^3 = 9.2 \times 10^{-8} \times 5.184$

Factor of safety = 2.5

d = 7.8 × 2.5 = 19.5 mm. 25.00 mm shaft diameter was selected.

viii. Belt design and selection

Since it is a 3-way pulley system, the conventional belt calculation formula will not be applicable. Equations according to William, (1953) will be considered to resolve the calculation for the belt length.

From Figure 4,

DA = Diameter of Pulley A, DB = Diameter of Pulley B, DC = Diameter of Pulley C

a is the distance between the centers of pulley B and C

b is the distance between the centers of pulley C and A

c is the distance between the centers of pulley A and B

Total length of belt = L

$$L = HJ + DE + FG + arclengths\ FE + GH + DJ \tag{9}$$

$$L = a' + b' + c' + I\alpha' + I\beta' + I\gamma' \tag{10}$$

$$\beta = \cos^{-1}[(c^2 + a^2 - b^2)/(2ca)] \tag{11}$$

$$\gamma = \cos^{-1}[(a^2 + b^2 - c^2)/(2ab)] \tag{12}$$

$$\alpha = \cos^{-1}[(38^2 + 78^2 - 64^2)/(2 \times 38 \times 78)] = 54.6°$$

$$\beta = \cos^{-1}[(78^2 + 64^2 - 38^2)/(2 \times 78 \times 64)] = 28.9°$$

$$\gamma = \cos^{-1}[(64^2 + 38^2 - 78^2)/(2 \times 64 \times 38)] = 96.4°$$

$$\alpha' = 6.284 - \cos^{-1}\left[{(6-15)}/{78}\right] - \cos^{-1}\left[{(6-5)}/{38}\right] - 54.6 = 233.44°$$

$$\beta' = 6.284 - \cos^{-1}\left[{(15-5)}/{64}\right] - \cos^{-1}\left[{(15-6)}/{78}\right] - 28.9 = 187°$$

$$\gamma' = 6.284 - \cos^{-1}\left[{(5-6)}/{38}\right] - \cos^{-1}\left[{(5-15)}/{64}\right] - 96.4 = 262.63°$$

Applying the equation of circumference of a circle to determine the corresponding value of α' β' γ' in meters.

$$C = 2\pi r \quad (13)$$

Iα' = 24 cm, Iβ' = 28 cm, Iγ' = 23.08 cm

Inserting derived values into Equation 9,

L = 63.21 + 37.99 + 77.48 + 24 + 50 + 23.08 = 276.7 cm = 2.767 m

Length of belt required is 2.767 m.

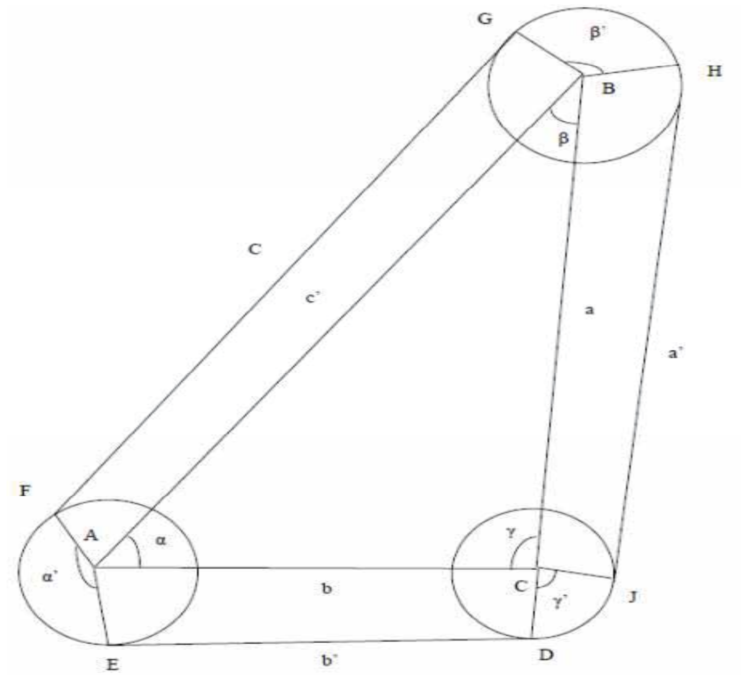

Figure 4: Schematic diagram of the belt and pulley

C. Principle of Operation

The maize dehusking and shelling machine developed is made up of the shelling unit, the blowing unit and the collecting unit. The shelling unit consists of the hopper with cover, the shelling cage and the sieve. The shelling unit is supported with the aid of a frame. The blowing unit is directly below the shelling unit. The shelling is accomplished by the shearing with the aid of the rotating pegs mounted on the cylinder, which force out the grains from the maize cobs holding them. Air is introduced into the shelled maize from the blowing chamber causing the chaff to be blown out through the bottom discharge plate. The clean maize leaves the machine at the output section of the machine (the lover discharge chute). The husk and cob are forced out of the machine via the upper discharge chute with the aid of paddle plates.

The pictorial view of the developed dehusking and shelling machine is shown in Figure 5 while Figure 6 shows the exploded view of the developed dehusking and shelling machine.

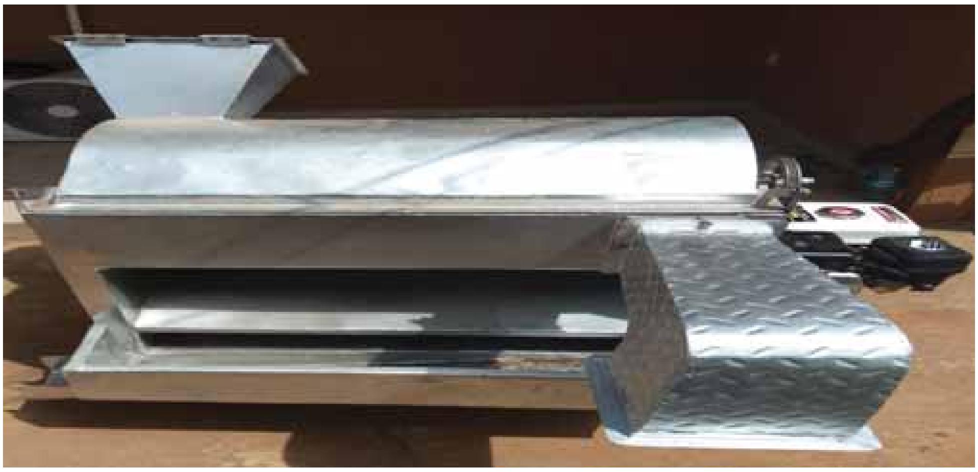

Figure 5: Pictorial view of the dehusking and shelling machine

Items	DESCRIPTION	QTY	Items	DESCRIPTION	QTY
1	COVER	1	11	PULLEY(BLOWER)	1
2	HOPPER COVER	1	12	ENGINE SEAT	1
3	HOPPER	1	13	DIESEL ENGINE	1
4	AUGER(THRESHING DRUM	1	14	V-BELT	1
5	SCREEN(CONCAVE GRILL)	1	15	AUGER PULLEY	1
6	FRAME	1	16	DISCHARGE CHUTE	1
7	MAIZE STORE PLATE	1	17	COB OUTLET	1
8	BLOWER HOUSING	1	18	COB DISCHARGE CHUTE	1
9	BLOWER BLADE	4	19	HINGES	2
10	BEARING	6	20	HOPPER ORIFICE	1

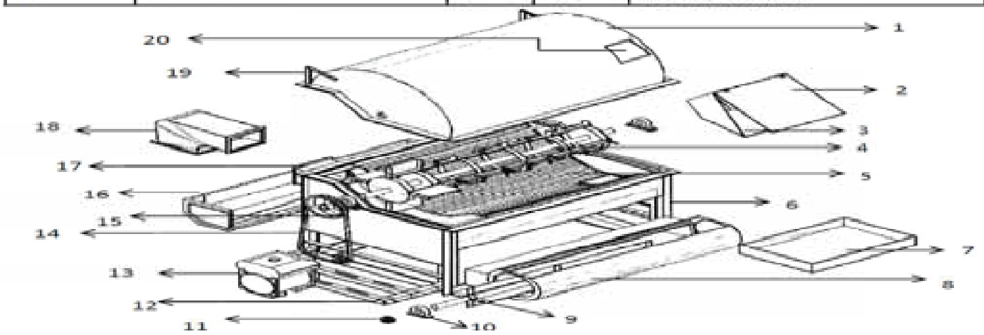

Figure 6: Exploded view of the dehusking and shelling machine

3.0 RESULT AND DISCUSSION

A. Performance Evaluation Test

In each run of experiments, 5, 7 and 10 kg of maize with reletively uniform dimesions was used. At the commencemnt of the experiment, the dried maize were subjected to measurement so as to arrive at relatively uniform number of maize in every experimental run. The shelling was carried out at speed of 576 rpm, 700 rpm and 800 rpm. The machine was first run under the no - load condition using a single phase, 1440 and a 1.8 kW petrol engine whereas the metallic drum spikes shaft was run at a speed of 240 rpm under the no-load condition.

B. Evaluation Parameters

The performance evaluation of the machine was determined using equation according to Abdulkadir *et al*., (2009).

$$\boldsymbol{Shelling\ Efficiency}\ (\%) = \frac{\boldsymbol{Wtm - Wum}}{\boldsymbol{Wtm}} \times \mathbf{100}$$
(20)

where; W_1 = weight of unthreshed cobs; W_2 = weight of cobs not well threshed.

$$\boldsymbol{Cleaning\ efficiency}\ (\%) = \frac{\boldsymbol{Wcb}}{\boldsymbol{Wcb + Wcl}} \times \mathbf{100}$$
(21)

$$\boldsymbol{Whole\ grain}\ (\%) = \frac{\boldsymbol{weight\ of\ grain\ collected\ at\ lower\ discharge\ chute(kg)}}{\boldsymbol{weight\ of\ grain\ fed\ through\ the\ hopper(kg)}} \times \mathbf{100}$$
(22)

$$\boldsymbol{Capacity\ of\ sheller\ (kg/h)} = \frac{\boldsymbol{Wt}}{\boldsymbol{t}}$$
(23)

i. Measurement of Parameters.

The weight of the maize was measured using an electronic precision scale (KD-TBE-1200) with a sensitivity of 0.01 g and maximum load of 1200 g.

Photo/contact type tachometer (LUTRON DT-2236B) was used in taking the machine speed.

C. Result

Results from experimental investigations carried out under the workshop conditions are discussed. The effect of different operational parameters like output capacity, whole grain percentage, cleaning efficiency and shelling efficiency of the dehusking and shelling machine are presented and discussed.

i. Physical Characteristics of Maize

The data on the size and diameter of samples are presented in Table 2. The average dimensions of maize cobs at 14 percent moisture content viz., length and width were 26.57 cm and 17.30 cm respectively. The average diameter of maize cobs at 14 percent moisture content viz., the maize cob diameter and maize grain diameter were 5.26 cm and 0.94 cm, respectively.

ii. Moisture Content of Maize

The initial moisture content of maize (with husk) after drying in three replicates and taking the average was found to be 33.1 % w.b. This value agreed well with the reports from the literature about thermo-physical properties of maize as investigated by Noche *et al*., (2011) and Adelaja *et al*., (2010). The moisture content of the maize was determined using the vacuum oven method at 110 ± 5 °C for 24 hours (AOAC 1990). The sample to be use for the experiment was dried to 14 % moisture content using sun drying method to reduce the moisture content.

Table 2: Physical characteristics of Maize

Replications	Cob length (cm)	Maize cob diameter (cm)	Cob width (cm)	Maize grain diameter (cm)
R_1	27.53	5.21	17.16	0.85
R_2	26.34	5.22	19.13	1.01
R_3	27.87	5.36	15.00	0.92
R_4	27.65	5.43	19.10	0.99
R_5	28.47	5.11	17.50	0.96
Mean	26.57	5.26	17.30	0.94

D. Shelling Efficiency

The shelling efficiency of dehusking and shelling machine based on 3 different machine speeds (576, 700 and 800 rpm) and 3 different loading capacities (5, 7 and 10 kg) were as shown in Table 3. It was observed that shelling efficiency increases as the machine speed increases with a decrease noticed at 800 rpm which was due to the breaking of the maize cobs as a result of the higher speed at this level leaving some grains unshelled.

This can be graphically observed in Figure 7 with shelling efficiency at 700 rpm been 99.67, 99.84 and 99.89 % for 5, 7 and 10 kg loading capacity respectively and a decline at 800 rpm having shelling efficiency of 99.51, 99.56 and 99.59 % for 5, 7 and 10 kg loading capacity respectively. Similar trend with higher shelling efficiency was observed in Naveenkumar, (2011), Adewole et al., (2015) and Patil et al., (2016).

Table 3: Performance evaluation of the dehusking and shelling machine

Speed (rpm)	576	700	800	576	700	800	576	700	800
Wtm (g)	5000	5000	5000	7000	7000	7000	10000	10000	10000
Wsm (g)	2113.06	2395.88	2439.87	3653.05	3878.13	3857.08	5333.05	5641.46	5783.81
Wdm (g)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wum (g)	15.00	16.67	24.33	20.59	11.18	31.14	30.66	11.31	40.96
Wmd (g)	749.86	544.50	528.37	920.74	782.86	753.76	1124.07	964.38	748.09
Wh (g)	1683.77	1685.01	1675.47	2077.03	2003.87	2012.87	3072.83	2909.87	3019.54
Wcb (g)	97.23	117.76	133.55	123.89	145.82	173.54	205.71	231.82	258.37
Wcl (g)	65.21	50.92	46.29	59.39	37.57	20.61	68.85	36.06	20.01
Shelling Efficiency (%)	99.70	99.67	99.51	99.71	99.84	99.56	99.69	99.89	99.59
Whole grain (%)	73.42	81.02	81.53	79.51	83.01	83.09	82.20	85.26	87.99
Cleaning Efficiency (%)	59.86	69.81	74.26	67.59	79.51	89.38	74.92	86.54	92.81
T (min)	3.28	2.69	2.29	4.11	3.28	2.95	5.21	4.45	3.35
Throughput (kg/hr)	91.46	111.39	130.81	102.11	128.05	142.21	115.16	134.83	179.10

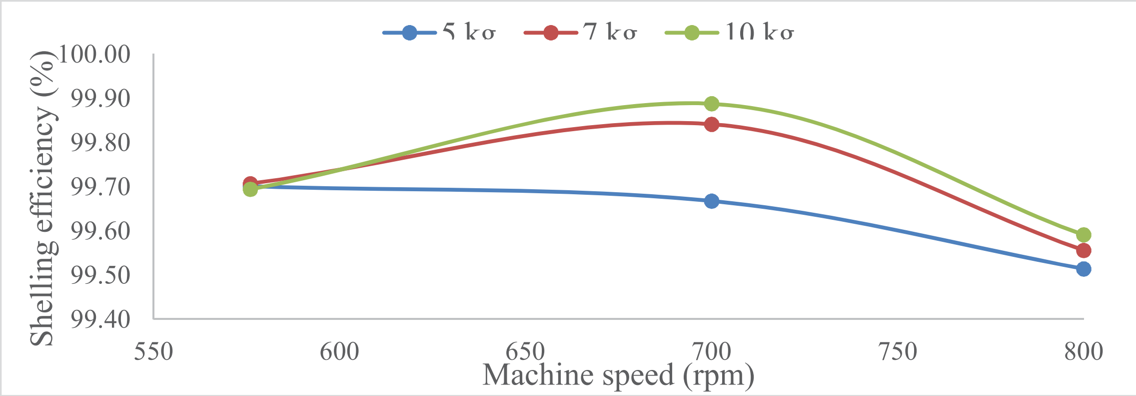

Figure 7: Shelling efficiency under different treatments

E. Percentage of Whole Grains

The whole kernel recovery was significantly affected by different machine speeds. The higher the machine speed, the higher the percentage recovery of whole kernels via the lower discharge chute.

This similar trend was observed by Vyavahare and Kallurkar, (2015) and Olaoye, (2002) when evaluating the performance of maize shelling machine. An increase in the speed of machine resulted in an increased number of rotation of shelling cage leading to an increase in rate of grain discharge via the sieve.

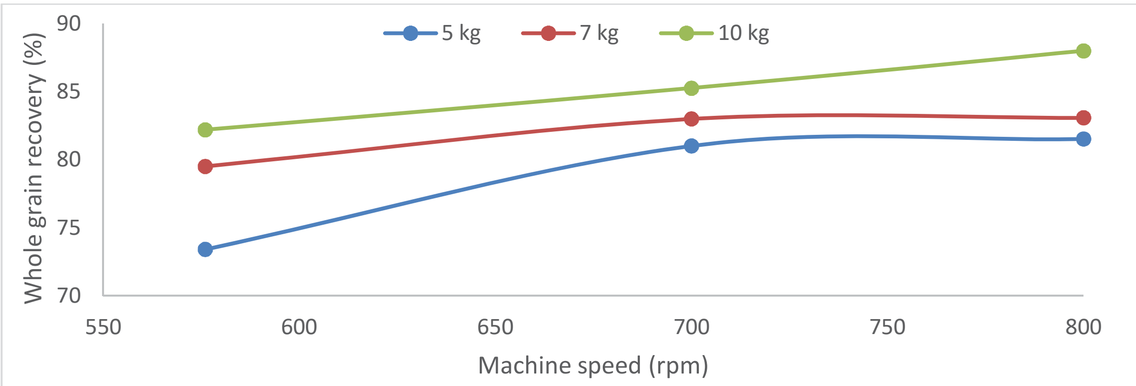

Figure 8: Whole grain recovery under different treatments

F. Cleaning Efficiency

Machine cleaning efficiency increases with an increase in machine speed as a result of resultant increase in blowing efficiency. This was observed for the three machine feeding capacity. Evaluation result as seen in Figure 9 also revealed that cleaning efficiency recorded for machine speed at 800 rpm was the highest having a percentage of 74.26, 89.38 and 92.81 at machine feed capacity of 5 kg, 7 kg and 10 kg respectively with the lowest cleaning efficiency obtained at 576 rpm with percentage of 59.86, 67.59 and 74.92 at machine feed capacity of 5 kg, 7 kg and 10 kg respectively.

The result and trends obtained agrees well with the observation of Kumar *et al*., (2002) and Olaoye (2012). Result of cleaning efficiency obtained was better compared with that of the two researchers as a result of the orientation and positioning of the blower. The improvement in the area covered by blower and the direction of air as against the dropping grain (counter direction blowing against the grain dropping by gravity) resulted in the increased cleaning efficiency of the developed machine.

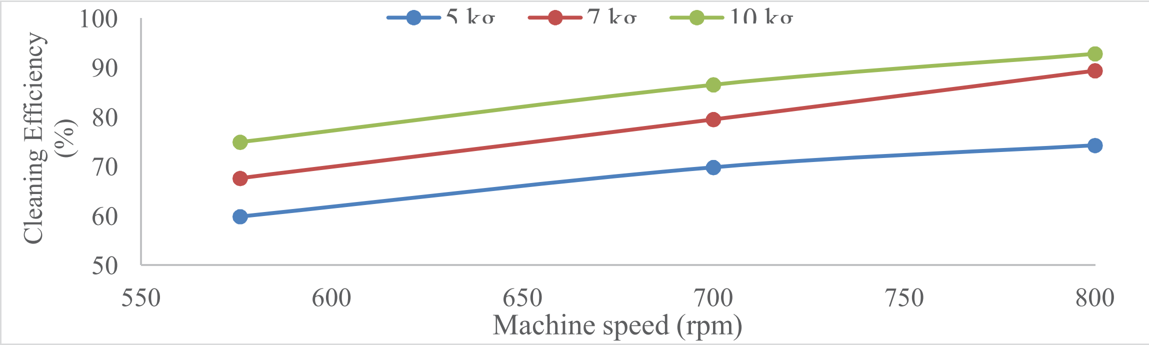

Figure 9: Cleaning efficiency under different treatments

G. Throughput Capacity

Figure 10 shows the graphical representation of throughput capacity of the dehusking and shelling machine. The average throughput capacity for the three feed rate increases with an increasing machine speed (Table 3). Results obtained are in tandem with a mechanically operated sheller reported by Mohammed, (2013). At 10 kg feed rate, the throughput capacity obtained were 115.16, 134.83 and 179.10 kg/hr for 576, 700 and 800 rpm machine speed respectively with the highest recorded at the maximum speed (800 rpm) for the experiment. The lowest throughput capacity for the experiment was recorded at 576 rpm at 5 kg feed rate (91.46 kg/hr). The result from the experiment revealed that the machine efficiency based on throughput capacity in higher than evaluation of a power operated maize sheller reported by Pathak, (2008) and Mohammed, (2013).

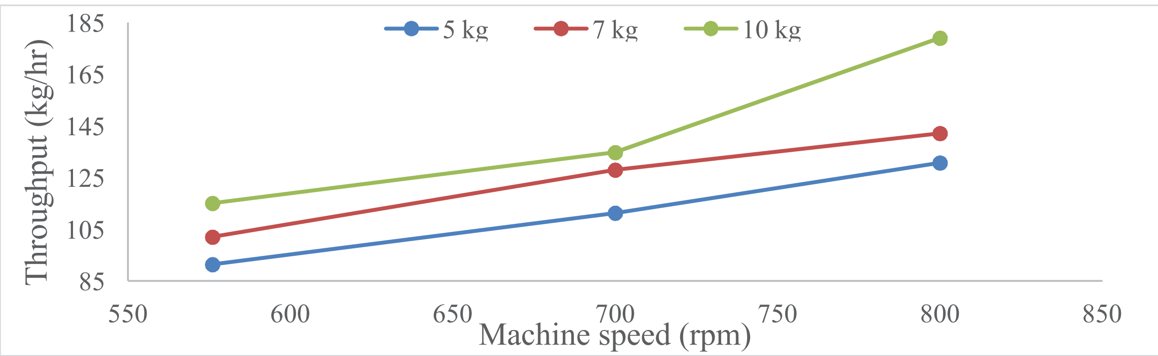

Figure 10: Throughput capacity of the machine under different treatments

4.0 CONCLUSION

This study was done to develop a shelling and dehusking machine for maize. The developed prototype dehusking/shelling machine was tested using maize with variation in rotational cylinder speeds and feed rate of dried maize of. The parameters like shelling efficiency (%), whole grains (%), cleaning efficiency (%) and throughput of sheller (kg/h) were recorded for each combination and data were compared statistically and graphically. By considering the performance of each combination, the total duration of shelling, labour and energy requirement, it was observed that at feed rate of 10 kg and machine speed of 800 rpm, the machine gave the best performance of dehusking and shelling.

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