Development of Motorized Corn Thresher

K. A. Olaiya[1], I.O. Alabi[2,], A.P. Okediji[3], K.A. Ajibola and M.O. Kareem

Abstract—A locally developed corn threshers is important to agro-allied industries who are challenged with low efficiency, high level of wastage, exerting of much labour and cost of procuring the imported ones. In this research, a motorized corn thresher was designed, fabricated and evaluated. The thresher has several co+mponent parts. The shaft is attached with a pulley connected with a belt to a 5.5 hp S.I. engine. The machine is movable with two tyres and can be driven from a farm location to another when attached to moving truck. The uniqueness of this design is that the cylinder drum has a 10mm spike tooth rods arranged longitudinally in 6 rows along the length of the shelling drum. Threshing is obtained by the impact of the spike tooth rod on the head. Cobs of 3-12 kg were loaded at different time into the hopper. The time taking to load and thresh the cobs were taken. A shelling efficiency of 78.93% was obtained with the throughput capacity 190.275 kg/hr, about 6% grain breakage and found to be better than some existing corn threshers. Labour productivity of the users will therefore increase resulting into improved timeliness of maize production and its market value.

Index Terms— Corn thresher, Grain breakage, Motorized, Shelling efficiency, Throughput capacity

1 Introduction

Cereal grains like wheat, barley, sorghum, rice and maize are commonly found in the world [1]. They are fruits of cultivated grasses belonging to monocotyledonous family Gramineae [2] and require plenty of rainfall and sun for optimum yield [3]. One of the most important cereal plants after wheat and rice in the world [4] and Nigeria in particular is maize, which is primarily known as corn in North America, and botanically as *zea mays*. It can be grown throughout the year where farming is mechanized with efficient irrigation system.

Maize is highly nutritious as it contains about 10% proteins, 4% oil, 70% carbohydrates, 2.3% crude fibre, 10.4% albuminoides and 1.4% ash. Maize has significant quantities of vitamin A, nicotinic acid, riboflavin and vitamin E [1]. It is an economically important crop used by the world's animal feed industry. Corn is a main forage plant for developing live-stock and poultry-farm over the world [5]. It can also be extracted and made into food and industrial products such as starch, oil, glue, and industrial alcohol [6]. In addition, the productions are produced by the corn for to use of a food-stuffs industry, medicine and at technical aims, those productions are popcorns, canned-foods, starch, crystallized sugar, spirit and other more production [5].

Currently, the demand for maize is increasing, arising from the expansion of the animal husbandry and animal feed industries, as well as from the practice of using maize as a raw material to create sources of energy such as fuel ethanol and biodiesel [6]. As its demand increases, cultivation area has to be expanded to meet production demand. According to [1], maize is widely grown throughout Nigeria. In fact, the climate in the south allows for it to be planted twice in the year. After the harvesting, 40% of harvested maize is lost every year due to the limitations posed for the farmers by the gross inadequacy of the right equipment for processing after harvest in Nigeria. In some cases most at times, the required agricultural machines are out of reach of the peasant farmers.

However, an increased quality of maize can be enhanced by devising an effective method of processing. The sequence of maize processing includes, harvesting, de-husking, shelling or threshing, winnowing, drying, bagging, and storage [7]. Harvesting is the plucking of cob from the plant and then the plant is harvested for animal feeding. After plucking the maize cob from the plant, maize cob is dehusked manually and then dried by using sun rays to reduce the moisture content. Shelling is a postharvest process [8]. Shelling is the removal of grains from the cobs by the initial impact, and rubbing action as the material passes through a restricted clearance between the cylinder, and concave bars [7] or process of removing maize kernel from cobs [9]. Maize shelling manually is a very exhausting and time-consuming task and cumbersome for large scale farming because it causes fatigue. The palm and fingers of farm women are at risk during maize shelling which decreases the efficiency of farm women. In fact the yield is always meager, and cannot meet the large demand of maize by the agro-allied industries. In addition, most mechanical threshers were designed for multi-grain threshing, which

- *Olaiya, K.A. is currently The Head, Department of Mechatronics Engineering in The Polytechnic Ibadan, Nigeria, PH-+2348059782951. E-mail: olaiya.kamorudeen@polyibadan.edu.ng*
- *Alabi, I.O. is currently a Lecturer at the Department of Automotive Engineering, Elizade University Ondo State, Nigeria, PH-+2348060849804. E-mail: ismaila.alabi@elizadeuniversity.edu.ng*
- *Okediji, A.P. is currently The Head, Department of Mechanical Engineering in Elizade University Ondo State, Nigeria, PH-+2348030527383. E-mail: adebunmi.okediji@elizadeuniversity.edu.ng*
- *Ajibola, K.A. is currently a Lecturer at Department of Mechanical Engineering in The Polytechnic Ibadan, Nigeria, PH-+2348034739297. E-mail: dear_kafayat@yahoo.com*
- *Kareem, M.O. is currently a Lecturer at Department of Mechanical Engineering in The Polytechnic Ibadan, Nigeria, PH-+2348030774941. E-mail: kareemolalekan5@gmail.com*

causes great damage to the maize seeds in addition to breaking the cob. The locally available thresher is equipped with a rotating threshing drum with beaters which damage the seed [8]. Thus, there is need to develop a thresher that will proffer solution to the marginalized farmers' problems arising during maize shelling. In addition, there are mechanized systems devised for easy stripping of grains from the cob by rubbing or beating, called shelling, but are too expensive for rural farmers. Hence, the need for a low-cost and improved maize thresher becomes necessary.

This research is aimed at designing a machine with greater efficiency than earlier designed prototypes, has simple structural parts for easy maintenance and can accommodate any size of maize.

In literatures several maize threshers like the hand operated, power (mechanical) operated, and tractors operated have been developed. Hand shelling is the conventional means of shelling maize. This is by striking a bag full of ears or heads with a stick. Maize and sunflowers can also be shelled by rubbing the ears or heads on a rough surface. Small tools, often made by local artisans, are sometimes used to hand shell maize. [10] described the use of pestle and mortar as a process by which the dry maize is put into the mortar and pestle is used to hit the maize with impact forces. With these tools, a worker can shell 8 to 15 kg of maize an hour [11]. [12] reported another means of threshing maize through Animals. Large quantities of maize were threshed by driving the animals (harnessed, in that case, to threshing devices) over and animals were used in threshing on the field by marching on the maize. Manual sheller is another means of shelling corn. It is relatively common and sometimes made by local artisans, permit easier and faster shelling of ears of maize. These come in several models, some of them equipped to take a motor; they are generally driven by a handle or a pedal. Use of manual shellers generally requires only one worker. With yields of from 14 to 100 kg/min, they are well-adapted to the needs of small scale production. Hand operated rotary maize shellers have been found suitable for small and marginal farmers for shelling maize, especially for seed purposes, as damage grains are lower in comparison to power operated maize shellers [13]. The main problems with these techniques are that they are not more productive and also corn seeds get damaged on large scale due to this seeds are not good for sowing at large extent [14].

However, engine powered technology involves the use of mechanical assistance in shelling the maize. This is necessary to facilitate speedy shelling of maize in order to reduce post-harvest deterioration, mechanical shellers are recommended, because hand shelling methods cannot support commercialized shelling [15]. Nowadays many small maize shellers, equipped with a rotating cylinder of the peg or bar types are available on the market. Their output ranges between 500 and 2000kg per hour, and they may be driven from a tractor power take off or have their own engine; power requirements vary between 5 and 15hp according to the equipment involved [2]. [16] developed an improved maize shelling machine that allowed easy flow of the maize towards the spikes inside the shelling cylinder at an improved feeding rate. The researchers utilized a 3-hp electric motor and also improved the ergonomic aspect of the design to obtain an efficiency of 96%. [17] designed an electrically powered corn shelling machine and suggested a 1.5Hp electric motor. [18] designed and developed a maize shelling machine which consists of a separate shelling chamber, threshing chamber, collecting tray and motor with a capacity of two horsepower (2 hp). [19] designed and fabricated a motorized maize sheller. The researchers performed perform test on corn having different moisture contain from 20% to 75% with 87.08% and 623.99kg/hr shelling efficiency and output capacity, respectively. [20] designed and fabricated a corn shelling machine with 2 hp electric motor. The researchers incorporated a blower powered by a separate electric motor connected to the discharge unit to separate the unwanted particles from the shelled corn. The machine was found to be about 79%t efficient with operating capacity of about 63.95kg/hr. [21] designed and fabricated a motorized corn shelling machine with improved power operated Sheller. The researchers employed an electric motor seat that provides adjustment so that the V-belt can be fixed easily to obtain a shelling efficiency, cleaning efficiency, grain recovery efficiency, Sheller performance index, total grain losses and output capacity of 87.08%, 95.89%, 95.48%, 91.55%, 2.96% and 623.99kg/hr. respectively at 13% moisture contents of corn and at 886rpm shelling speed. [8]) developed an electric corn shelling machine for small scale indigenous industries in Nigeria. The researchers employed a cost effective swift mechanism and pulley drive to obtain a shelling efficiency of 91.4%.

2 Materials and Methods

2.1. Materials Selection

Adequate care was taken in the selection of the materials for corn thresher. Materials were selected locally to make the material sourcing easier and cheaper.

The materials used for the construction of these components are mild steel plates, bars, pipes and electrodes due to its strength and rigidity. The machine was also coated with paint to curtail the effect of corrosion on it.

Bearings and other components that are vital to the design were careful selected.

2.2. Description of the Machine

This maize thresher was designed to cater for the needs of small scale farmers for domestic use or use by independent farmer on a daily hire bases for commercial purpose. The machine is movable with two tyres and can be driven from one farm location to another when attached to moving truck.

It is also of low cost when compared with imported threshers like combine harvesters, pickers or other foreign threshers which are very expensive and beyond the financial capacity of rural farmers.

The major component parts of this machine are the frame which serves as the support (for the hopper, threshing chamber; the bearings and pulleys), the hopper (Feeding chute), threshing drum, beaters, crine, fan box and blade, shaft, grain discharge unit, cob discharge unit, tyres and spark ignition engine.

A mechanical blower or fan is used to blow the shaft away from the cobs. It uses high speed blades to impart velocity to air hence, increasing the speed and the volume [1]. The shaft is attached with a pulley connected to the S.I. engine with a belt.

2.3. Design Consideration

The design consideration of this machine is based on three principles namely:

a) The gravitational dropping of the whole corn through the hopper to the rotating beaters and exit of the grains to the receiver.
b) The impact force delivered by the rotating beaters to the whole corn and motion of this whole corn along the length of the shelling drum.
c) The air generation and supply by the fan.

The uniqueness of this design is that the cylinder drum has a 10mm spike tooth rods arranged longitudinally in 6 rows along the length of the shelling drum. This kind of design improves the shelling efficiency and the quality of corn seeds obtained. Threshing is obtained by the impact of the spike tooth rod on the head. The factor that can make corn ear remain unthreshed in this kind of arrangement may be due to immaturity of the corn kernels or high moisture content of the corn ears.

2.4. Design Calculation

2.4.1. Threshing bar Design

Weight of the threshing bar, $w = mg$ (1)

Where, m = mass of the threshing bar, g = acceleration due to gravity.

The mass of the threshing bar, $m = \rho V$ (2)

Where, ρ = density of the threshing bar material, V = volume of the threshing bar.

Volume of the threshing bar, $V = \pi r^2 l$ (3)

Where, r = radius of the threshing bar, l = length of the threshing bar.

2.4.2. Shaft Design

A shaft is a rotating or stationary member, usually of circular cross-section rotating machine elements like gears, pulleys, flywheels, cranks, sprockets and other power transmission [3].

Shaft design consist primarily the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under operating and loading conditions. Therefore, in other to safeguard against bending and tensional stresses, the diameter of the shaft was determined from the equation [22]:

$$d^3 = (16T_e)/(\pi\tau_s) \quad (6)$$

$$T_e = \sqrt{(MK_m)^2 + (TK_t)^2} \quad (7)$$

Where:

d = Shaft diameter (m).

T_e = Equivalent twisting and bending moment (Nm).

τ_s = Allowable combine shear stress for bending and torsion (N/m²).

K_m = Combined shock and fatigue factor applied to bending moment and for rotating shaft loaded gradually the value is between 1.5 to 2.0.

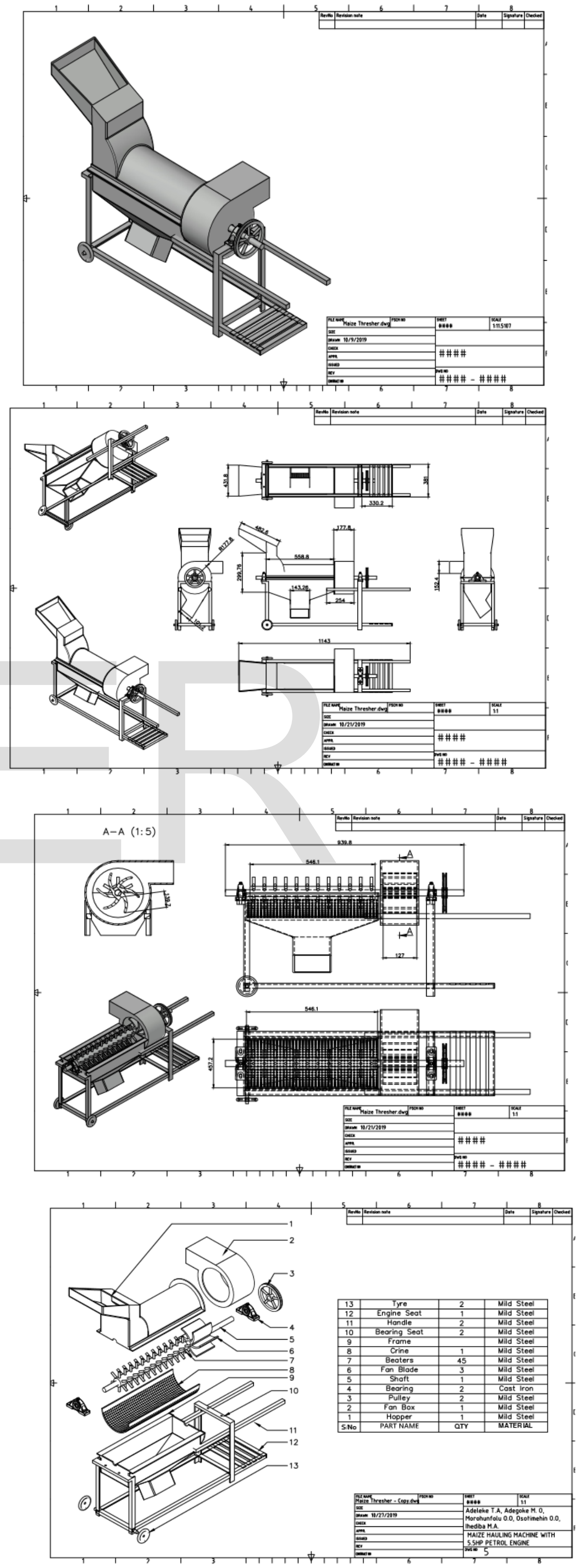

Fig.1: Isometric Drawing and exploded view of the corn thresher

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K_t = Combined shock and fatigue factor applied to torsional moment for a shaft loaded gradually, the value ranges is between 1.0 to 1.5.
M = Maximum bending moment (Nm).
T = Torsional moment (Nm).
Ss = Allowable stress and for shafts without keyway the value is 55 MN/mm^2.

The shaft of this machine has 45 beaters arranged longitudinally in 6 rows welded to it and a pulley mounted on it. It is supported on bearings. Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. Shafts are either solid or hollow. The following presentation is based on shafts of ductile materials and circular cross-section. The length of the shaft has been pre-determined at 814 mm.

2.4.3. Threshing Force

The force F required to thresh the maize along the length of the threshing bar is given by

$$F = m\omega^2 r \qquad (4)$$

Where m is mass of threshing bars, ω is the angular velocity of shaft. r = arm of the threshing bar

The angular velocity ω is determined by the equation:

$$\omega = {}^{2\pi N}/_{60} \qquad (5)$$

Where N is the speed of threshing which is in revolutions per minute.

2.4.4. Threshing Torque

The torque, T, is given by: $T = F \times r$ (6)
Where, F = threshing force; r = threshing arm.

2.4.5. Power Delivered by Shaft

Power P delivered by shaft along the length of threshing bars given by

$$P = T\omega \qquad (7)$$

where: ω = angular velocity (rad/s); T = threshing Torque (Nm).

2.4.6. Weight of the Pulley

The weight of the pulley on the shaft is given as:

$$m = \rho v \qquad (8)$$

Where m is the mass of the pulley, ϱ is the density of the pulley material and v is the volume of the pulley.
Weight is mass multiplied by acceleration due to gravity (g).

$$w\_p\ (weight\ of\ pulley) = \rho \times ((\pi D\text{^}2)/4) \times t\_p \times g$$
(9)

Where d is diameter of pulley, t_p is the thickness of the pulley. D is the diameter of the driven pulley

2.4.7. Torsional Moment, M_T

The torsional moment, M_T, is given by [3]

$$M\_T = 9550 \times kW/N \qquad (10)$$

2.4.8. Belt Selection

Appropriate belt selection will assist in effective power transmission. A belt provides a convenient mean of transferring power from one shaft to another. The effective pull on a belt is given by: $T = (T_1 - T_2)$ (11)

Where T_1 is tension on tight-side, and T_2 is tension on slack slide.
But $T\_1/T\_2 = exp(\mu\theta cosec\beta)$ (12)

Where β is the grove semi-angle, θ is the angle of lap or angle of contact at the smaller pulley, and μ is the coefficient of friction, 2β is the angle of the groove =30^0. The μ of friction for rubber belt on cast iron or steel operating on dry surface is μ = 0.3. β= 15^0. $\theta = \pi/2 = 3.142/2 = 1.571$

2.4.9. The power transmitted by belt

The power transmitted by belt is given by

$$P = (T_1 - T_2)v \qquad (13)$$

But

$$velocity, v = \pi dN/60 \qquad (14)$$

Where, d is the diameter of the shaft

2.4.10. Design for Bolts

The core diameter of the column threading was determined from equation 3.2 according to [23] and [24]:

$$p = \pi/4\ (d\_c\ )\text{^}2\ \sigma\_t\ n \qquad (15)$$

Where; P is the external load acting on the plate, d_c is the core diameter of the thread, σ_t is the allowable tensile stress for bolt material, n is the number of bolts. σ_t =165 N/mm^2.

Table 1. Maize thresher design parameters

S/N	Type	Symbol	Value
1	Threshing bar weight	W	0.329 N
2	Angular velocity	ω	134.06 rad/s
3	Threshing arm	R	0.2 m
4	Threshing Force	F	149.2 Nm
5	Threshing Torque	T	29.84 Nm
6	Power delivered	P	4000.35 W (5.36 hp)
7	S.I. engine	P	5.5 hp
8	Pulley weight	w_P	12.10 kg
9	Torsional moment	M_T	29.85 Nm
10	Tension in tight side	T_1	1824 N
11	Tension on slack slide	T_2	296 N
12	Belt type		V-belt

2.4.11. Tensile Stress Due to Stretching of Bolt

Initial tension in the bolt based on experiments may be found by the relationship in Eq. (16) as given by [24] and [25]:

$$P_i = 2840d\ (N) \qquad (16)$$

Where; P_i is the initial tension in a bolt (N), d is the nominal bolt diameter

2.5 Machine Fabrication Processes

The construction process involves cutting, shearing, drilling, welding, grinding polishing, assembling and spraying.

2.6. Bill for Engineering Measurement and Evaluation (BEME)

Table 2 shows the Bill for Engineering Measurement and Evaluation

Table 2. BEME

S/N	DESCRIPTION	QTY	UNIT PRICE (₦)	TOTAL PRICE (₦)
1	Bearings	4	500.00	2,000.00
2	Bolt, nuts and studs	50	100.00	5,000.00
3	V-belt	2	1000.00	2,000.00
4	Angle Iron, std.	2	1,500.00	3,000.00
5	Mild steel sheet std.	1	10,000.00	10,000.00
6	Pulley (big and small)	3	1,500.00	4,500.00
7	Transmission shaft (shelling and fan)	2	1,500.00	3,000.00
8	Mild steel rods (20mm, 35mm)	2	3000.00	6,000.00
9	Hacksaw blades and other consumables		2,000.00	2,000.00
10	5.5 HP petrol engine	1	30,000.00	30,000.00
Total				**62,500.00**

3 Testing and Evaluation

3.1. Testing

After the assembling was completed, the machine was properly lubricated at the threshing hub end and bearing for smooth running. It was then observed from any noise or vibration, which is normal to all belt driven machines.

Already preserved corn was purchased from Sango market in Ibadan, Oyo state Nigeria. The samples were cleaned to remove dirt and any other foreign materials. Whole undamaged corn with cobs were selected and weighed in batches of 3kg. Some samples were collected and used to determine the moisture content of the corn. Samples of weight 3kg, 6kg, 9kg and 12kg were fed into the machine and feed time recorded. The shelled corn was collected through the exit chute and the cobs also collected through the cob exit. The collected shelled corn and the cobs were weighed and the weights recorded. The experiment was repeated twice and average values noted.

3.2. Evaluation

The results obtained from the experiment was recorded and presented.

3.2.1. Performance analysis

The throughput capacity: the actual throughput capacity and the mechanic efficiency were determined. Corn cobs of 3, 6, 9 and 12 kg, respectively were measured using a weighing scale. A cob was loaded at a time into the hopper. The time taking to load and finish threshing the measured unthreshed maize was taken. The total weight of thresh grains was determined. The total weights of the broken or damaged grain, the weight of the cob and percentage mechanical damage were determined.

The feed rate and threshing rate were obtained as a function of time while the separation efficiency was found by subtracting the weight of cobs collected at the exit spout form total sample collected and multiplying by 100 %. Threshing efficiency was obtained using the equation [26]. All the results obtained were analyzed to obtain their best fit mathematical models and their attendant coefficients of determination (R^2) values:

$$E_{th} = \frac{M_s - M_{ut}}{M_s} \times 100\% \quad (17)$$

Where; E_{th} = Efficiency of threshing (%) M_s = Total mass of sample (kg) M_{ut} = Mass of un-threshed seeds (kg).
In addition, the threshing capacity (rate) TC was calculated by the equation given below [8]:

$$TC = (\text{average mass of shelled products})/(\text{average time taken}) \quad (18)$$

Table 3. Data obtained from designed machine test

Wt of corn (kg)	Feed Time (min)	Threshing Time(min)
3	1.05	2.24
6	2.03	3.38
9	3.09	4.17
12	3.29	5.15

From the results of the experiments carried out, as samples increased, threshing rate increased and more materials were pushed towards the exit spout. 190.275 kg was fed per hour while 120.48 kg of corn was threshed per hour. These values were found to be higher than 35.2 kg/hr and 63.6 kg/hr obtained by [8] and [20], respectively.

The average threshing efficiency was found to be 78.93 % while the average separation efficiency was 56.06 % as presented in Fig. 2. These values were found to be an improvement on the values obtained for human labour (as reported by [15]) where human mechanical efficiency was determined to be 45% at the biomaterial test weight of 20 kg with actually shelled grain weight of 15.8 kg. The design can be modified in order to find ways to improve the separation efficiency of the machine.

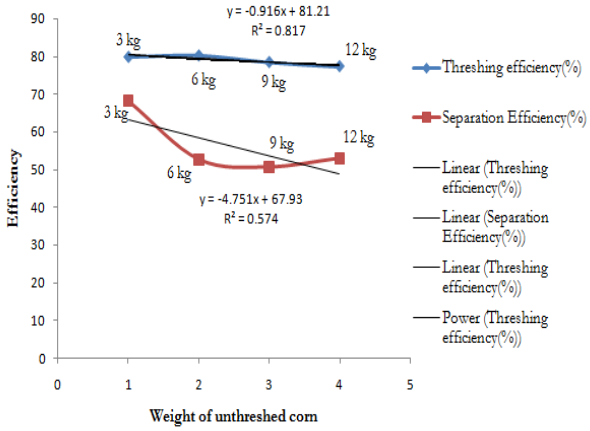

Fig. 2. Weight of unthreshed corn fed against efficiencies

3.2.2. Specific Energy Consumption (SEC)

The specific energy consumption in in W-hr/kg, was calculated using Eq. (18).

$$SEC = P/F\_R \qquad (19)$$

Where, P is the required power in Watts, and F_R is the feed rate of the feeder in kg/hr [6].

The average value of SEC was found to be 22.08 W-hr/kg.

3.2.3. Grain Breakage (GB)

GB is the ratio of broken grains, weighed after shelling, per the weight of grains sampled from the collection tray after cleaning [6], as seen Eq. (19).

$$GB = M\_B/W\_R \times 100\% \qquad (20)$$

Where, GB is grain breakage (%), M_B is the grain weight of all broken grains, and W_R is the random weight of shelled grain after cleaning.

An average of six (6) percent of the grains was found to be broken at the end of the experimental test carried out on the developed corn thresher.

4 Conclusion

The processing of agricultural product into quality forms not only prolongs the useful life of these products but also increases the net profit farmers make from such products. In this work, emphasis was placed on demand led design which involved understanding the need of the farmer and designing an appropriate system that meets that need. The specific objectives of the work are to design, fabricate, and evaluate the performance of a motorized corn thresher. Market days would also be used as an opportunity to show the farmers and agro-processors the advantage of using the corn sheller.

The following conclusions were drawn from this study:

1) The developed corn sheller has higher output and shelling efficiency were a bit higher compare to some existing corn shellers. Labour productivity of the users will therefore increase resulting into improved timeliness of maize production and its market value.

2) The machine Efficiency and Capacity of the designed and constructed maize thresher was tested and evaluated; the efficiency of 78.93 % was obtained with the throughput capacity 190.275 kg/hr.

3) An average of six (6) percent grain breakage was recorded which is an indication that the damaged grains obtained from the developed corn thresher's was less compare to some existing corn shellers.

4) The output of the maize shellers was best at the highest shelling speed and it requires at least one person to operate it.

5) The performance of the developed corn thresher was found satisfactory during the field evaluation.

5 Recommendations

Three recommendations are made from this study.

1) The highest output of the corn thresher was at shelling speed of 1280 rpm and the variations in percentage of damaged grain across shelling speeds were negligible. The developed corn thresher should be operated at around shelling speed of 1280 rpm. This will result into better labour productivity of the users and faster economic returns on the investment.

2) The developed corn thresher is recommended for packaging and eventual release to the agro-machinery manufacturers for scaling up purposes and subsequent marketing.

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