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(Review Article)

Design, fabrication and performance evaluation of a cowpea threshing machine

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Abstract

A cowpea threshing machine was designed, fabricated and evaluated in the Department of Agricultural and Bio-Environmental Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria. The machine was fabricated using locally available materials with the primary aim of reducing drudgery attached to the traditional method of threshing cowpea. The machine consists of the hopper, the threshing unit, the cleaning unit and the outlet. A 3-horsepower single phase electric motor served as the prime mover for the thresher. The machine was evaluated based on the varying operating speeds of 450 rpm, 550 rpm and 650 rpm and moisture contents of 13.5%, 14.5% and 15.5% respectively. The results showed that the machine efficiency increased with an increase in feed rate and a decrease in moisture content. An optimum level of 94.4% efficiency was observed at the speed of 650 rpm and moisture content of 13.5%.

Keywords: Design; Fabrication; Cowpea; Machine; Operating speed; Moisture content; Eficiency

1. Introduction

Cowpea (*Vigna unguiculata*) is an annual legume crop which is widely grown in Africa, Latin America, Southeast Asia and the Southern United States (Allen and Watts, 1998). The value of cowpea lies in its high protein content which enables it to fix atmospheric nitrogen and improves poor soils.

Many Nigerians earns their living through the cultivation of cowpea as it is one of the staple crops that provide much needed protein requirement in the dietary table (Olaoye, 2011). Cowpea as reported by Lawrence, (2006) could be prepared in several ways for consumption. Among them are boiling, grinding and processing into various diets based on individual cultural practice.

Production of cowpea is incomplete without threshing operation. Threshing of cowpea could be done through manual method via the use of sticks or pestles and wooden mortar on hard dry ground or rock or mechanical means using threshing machines to remove grains from the pods. To reduce the incidence of stones from the seeds during threshing, nylon, tarpaulin or leaf materials are spread before threshing is done. Manual threshing is usually characterized with wastage by breakage of seeds and high drudgery. After threshing, the seeds are usually cleaned by winnowing operation. The chaffs and the husks are used as feeds for livestock as hay or fodder (Olatunji, 2001).

Improper post-harvest operations, including threshing usually result to losses of up to 5% of the cowpea. (Bruce *et al.* 2001; Olaoye (2011). Good production techniques alone are not enough to solve the problem of field losses in production of cowpea, attention must also be paid to the suitable method of harvesting and threshing. To achieve

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optimum efficiency in the design of threshing machines, consideration must be given to feeding method, cylinder speed, concave to cylinder clearance and moisture content of the cowpea. (Kepner *et al.* 1978).

The results of a study by Biaou-Olaye *et al*. (2016).revealed an average threshing capacity ranging between 1326 and 2013 kg/h, mean fuel consumption ranging between 0.75 and 0.84 ml/kg; threshing efficiency of 100%. The seed damage of same study ranged from 2.63 to 16.45% with cleaning efficiency ranging from 95.57 to 96.79 % and the seed loss from 0.88 to 4.23 %. In a study by Abich *et al.* (2017), it was reported that increasing drum diameter, increased threshing efficiency as well as percentage mechanical grain damaged. The lowest grain mechanical damage of 1.68 % was recorded at 8.0 m/s operating speed and drum diameter of 200 mm. Maximum threshing efficiency of 97.48 % was achieved using the 400 mm diameter threshing drum in the study and the highest throughput per unit power consumption of 1568 [kg/h/ kWh-1]

There is now a general awareness in Nigeria and other developing countries that the rapid development of agriculture depends on the successful introduction of modern agricultural machinery. Many grain threshers have been developed, but reliable information and performance data on them are limited. Most of the imported threshers are very costly and beyond the reach of Nigerian small-scale farmers. Some were found unsuitable for threshing the local varieties. Therefore is the need to develop a local thresher that will be affordable to small-scale and medium farmers and processors, increase cowpea production, reduce drudgery as well as optimise the profit of farmers.

2. Design analysis & features

2.1. Capacity of the Hopper

The hopper is trapezoidal in shape. The volume of the hopper was determined as 0.0264 m^2 using equation 1.

$$Volume\ of\ the\ Hopper = {}^{1}/_{2}\,(A + B) \times H \quad \ldots\ldots\ldots\ldots\ (1)$$

Where A is the length at the top of the hopper; B is the length at the base of the hopper and H is the height of the hopper.

Capacity of the hopper was therefore determined as 15.05 kg using equation 2.

$$M = \rho_{cowpea} \times V_{hopper} \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Where M is the Mass of cowpea seeds; $\rho_{cowpea}$is the density of cowpea seeds; V_{hopper} is the volume of the hopper and the density of cowpea seeds varies between 535.6 and 569.9 kg/m^3(Yalcin, 2007).

2.2. Machine Shaft

Diameter of the shaft of the thresher was determined as 28 mm using equation 3 as expressed by (Agidi *et al.,* 2017). Therefore, a shaft of 30 mm diameter was selected

$$d^3 = \frac{16}{\pi s_s}\sqrt{(k_b M_b)^2 + (K_t M_t)^2} \quad \ldots\ldots\ldots\ (3)$$

Where;
d is the Shaft diameter;
s_s is the allowable stress, 55 x 10^{-6} N/m^2 for mild cast steel without key ways;
M_b is the maximum bending;
K_b is the shock and fatigue factor for bending moment, 1.5;
K_t is the shock and fatigue factor for torsional moment,
M_t is the maximum torsional moment.

2.3. Power Requirement

The power requirement of the machine was determined with the expression by Kurmi and Gupta (2005) as presented in equation 4.

$$P = \frac{2\pi NT}{60} \quad \ldots\ldots\ldots\ldots\ldots\ (4)$$

Where P is power (Watt); N is shaft speed (rpm) and T is torque required to turn the shaft at the circumference of the driven pulley (Nm). Power required to drive the shaft is 1.84 kW

Assuming, 10% power loss due to friction, total power required is 2.02 kW (2.71 horsepower)

Therefore, an electric motor of 3 horsepower was selected.

3. Machine description & operation

The cowpea threshing machine (Fig.1) consists of the frame, the hopper, the threshing unit, the cleaning unit the outlet tray and the power transmission unit. The frame is made up of 2 mm angle iron. The frame holds other components of the thresher together. The hopper is made up of 1.5 mm thick galvanised metal sheet, it is rectangular in shape. The threshing unit comprises of beaters enclosed in the cylinder in which the lower part is perforated to have slots through which the threshed seeds and the chaffs can fall through to the cleaning unit for proper cleaning and separation. The cleaning unit consists of a centrifugal fan which generates air blast for appropriate cleaning using the terminal velocity principle. The winnowed and threshed seeds are collected through the outlet tray. The thresher is powered by 3 horsepower electric motor using the belt and pulley transmission system.

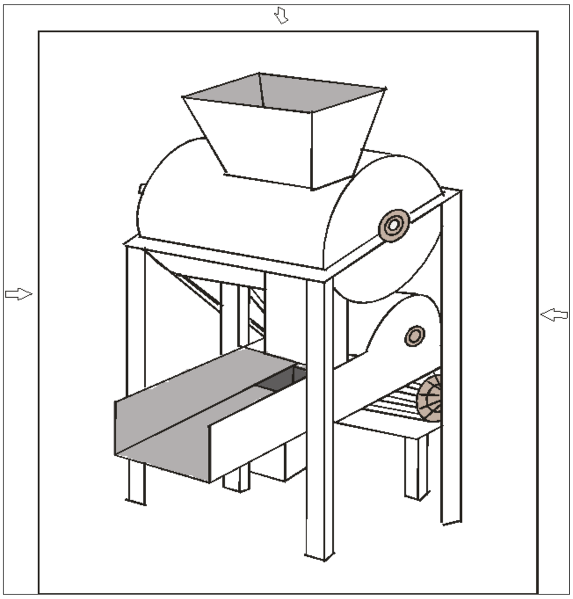

Figure 1 Isometric View of the Cowpea Thresher

4. Machine performance test

The performance test of the cowpea thresher was carried out to determine the effects of machine speed and moisture content of the cowpea seeds on the performance of the thresher. In the first experiment, varying speeds of 450 rpm, 550 rpm and 650 rpm at a constant feed load of 15 kg and a constant moisture content of 13.5% were used. In the second experiment, varying moisture contents of 13.5%, 14.5% and 15.5% were used at a constant feed load of 15 kg and a constant machine speed 650 rpm as recommended by Ogunlowo and Bello (2005) for optimum operation of a thresher

The machine efficiency and the machine capacity of the thresher were determined using equations 5 and 6 as expressed by Oladimeji and Lawson (2019)

$$Machine\ Capacity = \frac{\text{input weight}}{\text{time taken}}\ (kg/s) \ldots\ldots\ldots\ldots (5)$$

$$Threshing\ Efficiency\ \% = \frac{\text{Ws}}{\text{Wi}}\ X\ 100\ \ldots\ldots\ldots\ldots (6)$$

Where;

W_s is weight of threshed cowpea (kg)

W_i is Initial weight of cowpea (kg)

5. Results and discussion

The results of the machine performance test are as presented below.

5.1. Effect of Machine Speed on the Efficiency of the Thresher

Fig. 2 shows the effect of machine speed on the efficiency of the thresher. It was observed that the threshing efficiency increased with an increase in the machine speed. The highest threshing efficiency of 94.50 % was recorded at 650 rpm and moisture content of 13.16%. This is in conformity with the result of a study by Biaou-Olaye *et al*. (2016).The relationship between machine speed and the efficiency can be described as linear with coefficient of determination, r^2 of 0.9765 that shows that a good correlation exists between the two variables.

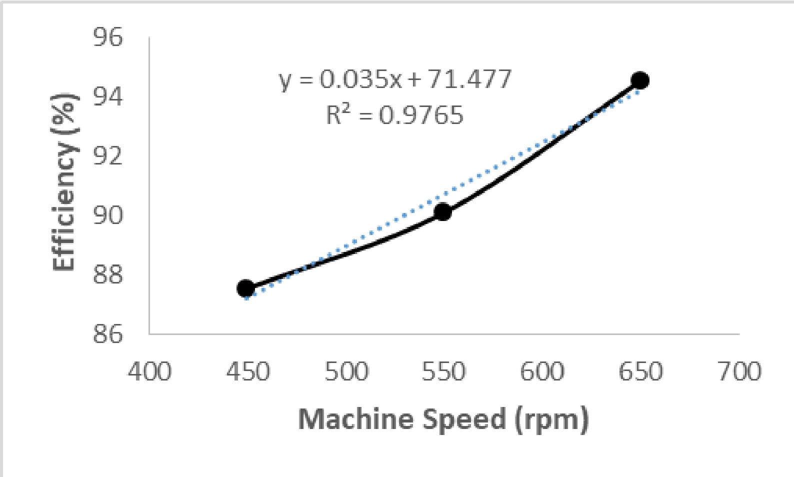

Figure 2 Effect of machine speed on Efficiency of the Thresher

5.2. Effect of Machine Speed on the Capacity of the Thresher

As presented in Fig.3, a linear but inverse relationship was observed between machine capacity and machine speed in which the machine capacity decreased with an increase in machine speed at constant moisture content of 13.5%. Highest machine capacity of 128 kg/h was recorded at machine speed of 650 rpm. This is less than the output capacity reported by Abich *et al*. (2017). This may be due to difference in the size of the thresher. The coefficient of determination r^2 of the relationship is 0.9304. This is a good proof that a perfect correlation exists between the machine speed and the machine capacity.

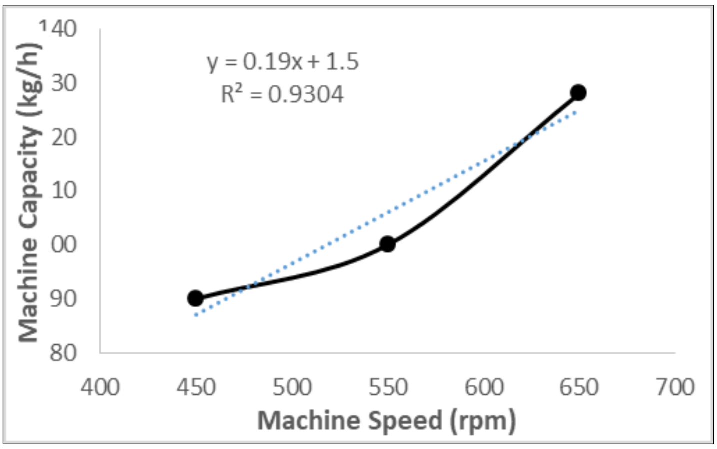

Figure 3 Effect of Machine Speed on the Machine Capacity

5.3. Effect of Machine Speed on the Loss Percentage of the Cowpea

A linear relationship was observed between the machine speed and the percentage loss as presented in Fig. 4 with coefficient of determination, r^2 of 1. The percentage loss increased with an increase in the machine speed. The highest percentage loss of 12.46% was recorded at the machine speed of 650 rpm while the lowest percentage loss of 7.40 % was recorded at the machine speed of 450 rpm. This is close the range of loss reported by Biaou-Olaye (2016) and Olaoye(2011).

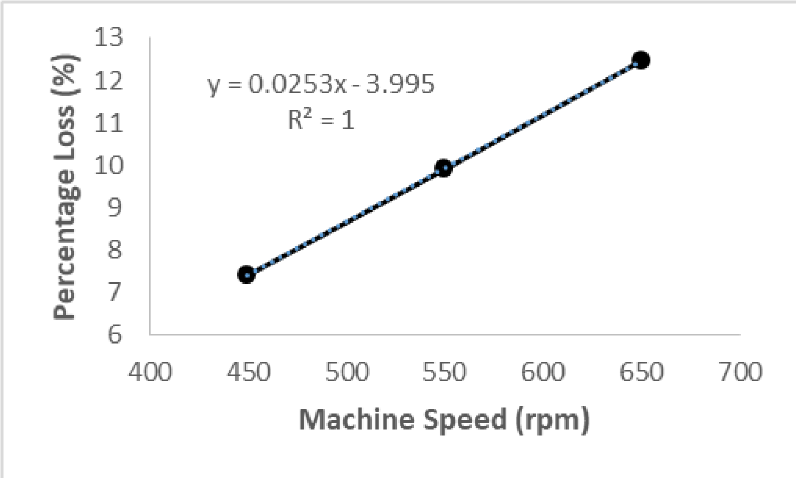

Figure 4 Effect of Machine Speed on the Percentage Loss of Cowpea

5.4. Effect of Moisture Content on the Machine Efficiency

A linear but inverse relationship was observed between the moisture content of cowpea and the efficiency of the thresher as presented in Fig. 5. The efficiency increased with an increase in the moisture content of the cowpea with coefficient determination r^2 of 0.9535. This is similar to the study by Ishola *et al*. (2020) in a research on the development and preliminary evaluation of Jatropha curcas decorticator. Highest efficiency of 91.50% was recorded at a moisture content of 13.50% and the lowest efficiency of 74.50% was recorded at a moisture content of 15.50%.

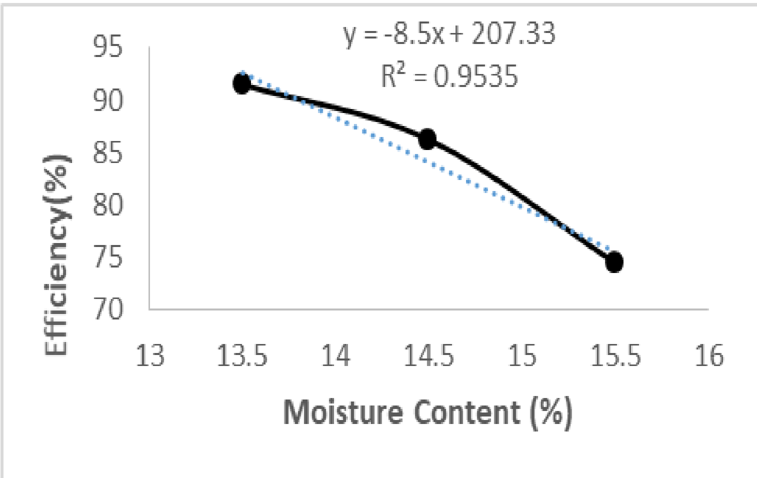

Figure 5 Effect of Moisture Content on the Machine Efficiency

5.5. Effect of Moisture Content on the Machine Capacity of the Thresher

A linear relationship was observed between the moisture content and the machine speed as presented in Fig. 6 with coefficient of determination r^2 of 0.9408. The machine capacity increased with an increase in the moisture content. This is contrary to Asante *et al*. (2017) that reported that the output capacity increased with a decrease in the moisture content of the cowpea. The highest machine capacity of 117.47 kg/h was recorded at a moisture content of 15.6%.

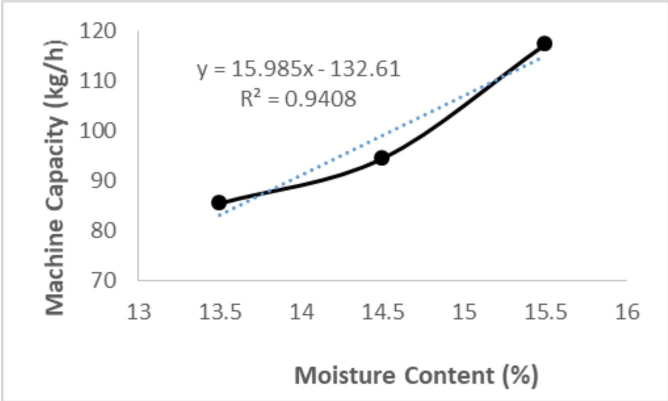

Figure 6 Effect of Moisture Content on Output Capacity

5.6. Effect of Moisture Content on the Percentage Loss

A linear relationship was observed between the moisture content and the percentage loss as presented in Fig. 7 with coefficient of determination, r^2 of 0.9994. The percentage loss increased with an increase in moisture content. This is not different from the trend reported by Asante *et al.* (2017) on performance evaluation of a cowpea thresher at various moisture contents. The highest percentage loss of 10.65% was recorded at the moisture content of 15.5% while the lowest percentage loss of 6.25% was recorded at the moisture content 13.5%.

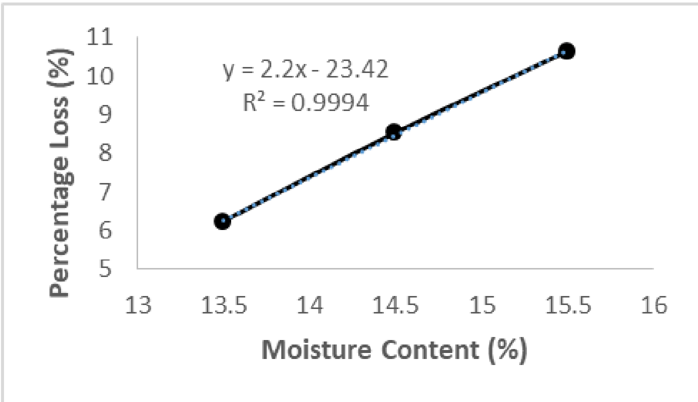

Figure 7 Effect of Moisture Content on the Percentage Losses

6. Conclusion

A cowpea thresher was designed, fabricated and tested at the Department of Agricultural and Bio—Environmental Engineering Technology, Rufus Giwa Polytechnic, Owo, Nigeria. The thresher was tested suitable for effective separation of the seeds of cowpea from the husks. The evaluation results revealed optimum performance of 94.50% machine efficiency; 128 kg/h machine capacity and average percentage loss of 7.40% at a machine speed of 650 rpm and 13.50% moisture content.

Good correlation exists between the dependent variables (machine efficiency, machine capacity and the percentage loss) and the independent variables (machine speed and moisture content of the cowpea). The development and performance, the thresher will specifically serve as a means to alleviate the problem associated with cowpea production and processing and generally reduce the problem of food security in Nigeria. It is therefore recommended for both small and medium scale farmers and processors.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict f interest

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