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Research/Technical Note

Design, Manufacture and Performance Evaluation of a Soybean Paddle Thresher with a Blower

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Abstract: Soybeans threshing is traditionally done by hand beating with a wooden stick on a hard surface which is a drudgeries operation which leads to time-consuming, grain damage and grain loss due to shattering for small-scale farmers. Therefore, a soybeans manual thresher (Pedal operated) machine attached to a blower was designed, manufactured and its performance evaluated to help eradicate this problem by reducing labor, improve post-harvest, and increase income to small-scale farmers. The thresher consists of a hopper, drum, shaft on bearings, frame, beaters, blower, chain, and sprocket power transmission, pedal and seat. The thresher was fabricated with sheets and angle iron and the mechanism is based on a combination of impact, compression, and shear. Two levels of moisture content level were combined to evaluate the performance of thresher in terms of its capacity, threshing efficiency and percentage grain damage. The combination of dried and wet sample mixture at a feed rate of 25kg yielded maximum threshing capacity of 96 kg/hr, 98.6% maximum threshing efficiency and minimum percent grain damage of 3.5% results was recorded, which was very satisfactory.

Keywords: Soybeans, Pedal Operated, Thresher, Blower

1. Introduction

Soybean is certainly of a great economic and social importance worldwide. Soybean provides about 64 percent of the world's oilseed meal supply and is the major source of oil, accounting for about 28 percent of total production [1, 2]. Soybeans were introduced in Northern Ghana in 1910 and production rate in Ghana is above 50,000 metric tons per annum [3, 4]. Products such as Soy oil, soya mince, stock feeds, soy cake, soy milk cheese as well as soya wax are some of the products derived from soybean [2]. However, Soybean production has faced harvesting challenges especially among the small-scale farmers who are poorly mechanized. This small-scale farmer cannot afford to hire tractors for their field activities, hence most of the soybean crop getting lost through shattering or affected by rains because of late harvesting. Soybeans seed contains about 20% oil and 34-36% protein which makes it an economically important seed [5]. It is grown for processing into edible oil and the residue from oil extraction is a high protein meal, a critical ingredient for stock feeds. It also consists of 30% carbohydrates, vitamins, minerals and excellent amounts of dietary fiber [6]. Though many proteins can be obtained from others crops soybean is the only available crop that provides an inexpensive and high-quality source of protein comparable to meat, poultry, and eggs.

Majority of soybeans cultivation is done mostly in Northern Ghana where the land is very fertile for yielding a bounty of maize, beans, pigeon peas, millet, barley, wheat, cotton and a variety of vegetables and therefore majority of indigenes form this part of the country are small-scale farmers who rely mostly on agriculture for both food and income. However, these small-scale farmers employ few labor saving devices in their farming operations due to low income and high fees required to hire motorized labor-saving machines. Throughout generations, the traditional methods of harvesting of beans have been threshed using a log. Threshing is the removal of the grains from the rest of the plant. Usually, the threshing is done by beating it on the ground with sticks. Even though such tools are simple and cheap but this practice is physically demanding and time-consuming. It also damages grain, resulting in broken kernels and dirty grain that has both low value and a short storage life [7, 8].

[9] designed a paddy thresher with plastics components for small scale production in India. [10] also came up with a hand-operated seed thresher for heavy-seed crops whereas [11] designed a soybean thresher to enhance germination rate. Though the design and manufacture of threshers has been evolved in Africa such as tractor operated, engine operated, manual operated etc. but this has not trickled down well in rural areas of Ghana. Therefore, the objective of this research is to design and manufacture a simple mechanical thresher machine operated by a bicycle or (a small motor) which will improve not only the quality, in terms of damage and yield, but also the efficiency of human effort required and improve ergonomics, while increase income for small-scale rural farmers. These would also fill the gap between traditional methods and highly sophisticated machines which are mostly scarce, inappropriate for use by rural farmers due to their high cost and maintenance problems.

2. Materials and Methods

2.1. Description of Machine and Operation

The pedal operated thresher consists of a cylinder, concave sieve, beaters, drum shaft, hopper, the main frame, chains and sprockets drives, bearing and bearing housing and a blower. The entire Thrasher is made from local materials. The seat and hand rest of the thresher was designed in such a way that the spinal column from the vertical plane and arms angle between the upper and lower arm of the operator remains in a comfortable position during operation. The height of the hand rest and seat can be adjusted according to the need of the operator.

The chain and sprocket system was found to effectively transmit power from the pedal to the threshing drum shaft. The beaters are 20 x 10 mm rectangular mild steel bars welded on the periphery of the drum shaft which provides the required beating action for detaching the soybeans from the straw. The transmission system of the thresher was equipped with a set of five sprockets and three chains. Power is transmitted from the pedal to the threshing cylinder through a chain and sprocket system having a speed ratio of 1:8, based on ready-made sprockets available in the market. The threshing drum diameter was 150 mm at the tip of the rectangular bars. A safety cover was also provided in the thresher to protect the operator as per norms (IS:9020) [12] and to save the beans losses during operation.

The cylinder is designed by rolling a sheet of mild steel of 1mm thickness. The concave sieve followed with similar design and material but with perforated drill holes. The hopper is the inlet that allows the soya-beans stalks to be feed in the threshing chamber. To get the concave shape of the hopper, a trapezoidal shape is marked out and cut to size of a 1mm thickness of mild steel, folded and welded to shape. The main frame of the machine was made using the combination of a standard angle iron of 40mm x 40mm x 6mm with a height of 700mm, a width of 400mm and breadth of 500mm; and a mild steel pipe (50/30mm diameter). The limiting values of the rectangular bars (beaters) spacing and the tip height were based on an old paddy thresher. The thresher chamber consists of the concave sieve and the drum shaft with attached beaters. The pedal rotation speed of a normal man, operating on the thresher, was found to be approximately 55min^{-1}.

Typically, threshers are classified in accordance with the method of feeding, drum design and the power source [8]. The design of the drum falls under the following:

1) Peg Tooth Thresher
2) Rasp Bar Thresher
3) Wire Loop Thresher

This research design is based on the Peg Tooth Thresher methodology which is design with parallel bars attached to the drum shaft as shown in figure 2. The thresher mechanism consists of chains and sprockets which are attached to a design bicycle frame with a provision for 1-kilowatt motor engine attachment if desired. The machine is powered by paddling which rotates the drum shaft armed with teeth which strip the beans from the stalks as it passes between the revolving drum and a metal grate, (known as the concave sieve). The threshing action is achieved based on a combination of impact, compression and shear force created in the chamber. The machine was designed with a blower in operation, the grains are separated by the blower fan which blows a column of air horizontally past the grains that drop vertically and force the chaff through the chaff- discharge outlet. This action is achieved because of the density difference between grains and the chaff.

Figure 1. *Photo of the soybean thresher machine.*

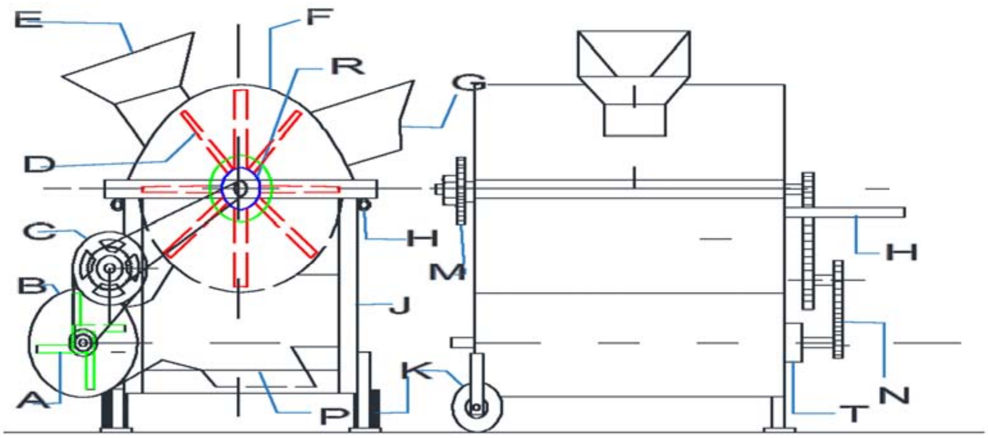

Figure 2. *Front and end elevation of the thresher machine.*

Table 1. *Parts List of the Thresher Machine.*

S/N	Part Number	Name of Part	Material Made of Part	Parts Number Off
1	A	Blower Fan Blade	Mild Steel	4
2	B	Blower House	Mild Steel	2
3	C	Sprocket	Mild Steel	5
4	D	Beaters	Mild Steel	40
5	E	Hopper	Mild Steel	1
6	F	Cylindrical Cover	Mild Steel	1
7	G	Chaff Outlet	Mild Steel	1
8	H	Machine Handle	Mild Steel	2
9	J	Frame	Mild Steel	1
10	K	Roller Wheels	Rubber	2
11	M	Sprocket for External Connection	High Carbon steel	1
12	N	Roller Chain Drive	Plain carbon steel	2
13	P	Grains Outlet	Mild Steel	1
14	Q	Bearings	Chrome Steel	4
15	R	Drum Shaft	Mild Steel	1
16	T	Blower Shat	Mild Steel	1

2.2. Design Considerations

For the economical and efficient design of the machine, the design must perform well under expected and worst-case conditions. Therefore, the following design factors were taken into consideration:

1) The drum shaft of the thresher will be subject to tension, compression, torsion, and bending. These loads are considered and calculated under service conditions and the locations of critical loads and location of joints away from high-stress areas of the various machine components for reliability.
2) Materials selection was based on cost and availability of local materials without compromising their quality. This to ensure that the thresher will be less expansive, maintenance and parts replacement can be readily available and affordable for the farmers.
3) In the design of the machine for the purpose of optimal threshing of the chaff from the grains, crop factors such as moisture content and size were considered.
4) Factors such as operator height, weight, and age were critically considered in the design and required a minimum pressure for optimum efficiency. The manual operation of the machine was selected as a result of the frequent power outages experienced in Ghana and will be helpful in the rural areas where lots of soya-bean farming activities are done.
5) Robustness, stability, vibration, and noise are factors considered in the design of the thresher under service conditions for possible failure in certain parts or components of the whole assembly.
6) Safety precautionary measures for the end user were considered, so the thresher design for easy assembly and disassembly, with easy ergonomics to use and operate.

2.3. Design Analysis

As a manual powered mechanical thresher, the expected maximum throughput is 100 kg/h. If higher throughputs above this are required, an attachment is provided on the machine for a mount of a small engine [1 kW (1.34hp)] to power the thresher. The main designs of the machine were the hopper, drum shaft, the main frame, and the blower.

2.4. The Hopper

The hopper is designed and fabricated in a trapezoidal shape made from a mild steel sheet plate of 1 mm thickness. The top area size of the hopper is design to 400mm^2, the base size of 150mm^2 and height of 220mm at an angle of 45°. This angle is suitable for easy flow and maximum feed during operation.

2.5. Shaft Design

The shaft is a rotating machine component that is used to transmit power from the motor (bicycle) to the blower and the thresher. The need for a solid circular shaft was necessitated for analysis for its combined bending and torsional stresses.

The following factors were considered in the shaft design;

1) It must be rigid enough to withstand the twisting and bending moment
2) The shaft should be durable and tough
3) The shaft must be wear resistance and strong enough to withstand all the shock loads during service.

The calculation for the shaft diameter was selected using the ASME code equation for a solid shaft having little or no axial loading [13].

$$d^3 = \frac{16}{\pi\sigma_s}\sqrt{\left(k_t M_t\right)^2 + \left(k_b M_b\right)^2} \quad (1)$$

Where σ_s= Ultimate stress of mild steel with keyway, (N/m^2), d_o= shaft outside diameter, (m), k_b = combined shock and fatigue factor applied to bending moment, k_t = combined shock and fatigue factor applied to torsional moment (for rotating shaft with suddenly applied load), M_t = maximum torsional moment (Nm), M_b = maximum bending moment (Nm).

2.6. The Drum and Beaters

The thresher consists of a rotating drum armed with teeth (beaters). This unit is fabricated together and consists of a shaft 750mm length made up of 25mm mild steel rod and a 175mm diameter pipe. Attached to the shaft are the beaters made of 12mm diameter mild steel rods which are arranged alternately at a spacing of 100mm from one another so as in operation, strip the grains from the stalks as it passes between the revolving drum shaft and the metal grate, thereby threshing the stalks from the grains. The beaters were designed with (20 x 10mm) parallel bars welded at different angles and spacing along the drum shaft based on an old paddy thresher.

2.7. The Frame

The frame supports the thresher in position and is made from a sound and solid 40mm x 40mm x 6mm angle iron mild steel. Angle iron was selected because is stronger than non-structural steel, the two perpendicular flanges work in conjunction to give angle iron cross-sectional structural integrity, resistance to bending from pressure applied from the top or bottom left or right. The two flanges that make up the angle create a compound area which makes it most resistant to the moment of inertia. The lengths were cut to size and welded to form the frame. The height of the frame is 950mm and width of 750mm. To optimize the strength of the frame, pieces of the angle iron were welded together at 90° angles and bracing the angles of the welds with short pieces at 45° angles to reduce any susceptibility to twisting.

2.8. The Blower

A properly functioning blower is an essential for the separation of chaff from the grains. The blower consists of 60 mm diameter mild steel shaft which rests on ball bearings at the two ends on the rectangular stand. The four blades (steel plates) which are arranged and attached on the shafts periphery alternately at a 90° angle along on the shaft (rotor) which is milled square at the center of the shaft so as to generate centrifugal force to blow the wind when in operation. When the rotor rotates it generates air which is pushed into the chamber and as the chaff are lighter in weight than the grains, they are blown away leaving the only the grains for collection. When in service, the blower force air through the outlet vent of the thresher between 50 and 100 cubic feet per minute depending on the person paddling the machine and also maintain a static pressure of between 10 and 30 ounces. The blower housing was fabricated with a 1mm sheet metal with a diameter of 300mm.

3. Performance Test Procedure

To ensure various components functioned properly, the machine was set up and was easily powered and operated by one person. This was done five minutes without load, the fixed and moving blades exhibited good clearance, and the bearings were well mounted, with a smooth movement of the drive shaft after adjustments were made.

Afterward, a considerable quantity of soybeans/stalks mixture was purchased from Bimbila in the Northern part of Ghana where is widely cultivated. The soybeans stalks were prepared in batches of sample mixture for the performance test. 25 kg mixture sample was randomly fed through the hopper into the machine and about 300 kg of the soybeans stalks in total were used for the experiment. For the experimentation, two different moisture content levels were varied (dry and wet) with a corresponding operation speed of (47, 71 and 97) m/min respectively for easy threshing of the soybeans from the stalks. Table 2 shows the experimental plan for evaluation of the parameters. Thereafter, the quantity of threshed and unthreshed and damaged soybeans from the two outlets was carefully sorted out and weighed at three different speeds for each set of operation. This procedure was repeated for the respective times for each moisture content sample. For the determination of the threshing efficiency, percentage soybeans breakage and throughput capacity were evaluated under each condition. In the analysis of the performance, the following terms and terminology were adopted in finding the evaluated parameters;

Threshing Efficiency, E_T;

$$E_T = (W_s + W_f)/W_s \; 100 \qquad (2)$$

Where W_s = weight of sample mixture fed into the machine (kg)

W_f = weight of grains collected after threshing (kg)

Percentage grains breakage, P_b;

$$P_b = T_d \;/\; (T_d + T_u) \times 100 \qquad (3)$$

Where: T_d = weight of cracked and damaged grains (kg)

T_u = weight of cracked and undamaged grains (kg)

Throughput capacity, C_c is express as

$$C_c = S_T/T_T \qquad (4)$$

Where: Where, S_T = the total weight of the grains fed into the machine (kg) and T_T = the total time take by the threshed mixture to leave the discharge outlet (hr).

Table 2. *Experimental plan for evaluation of the thresher.*

S/N	Variables	Level
1	Moisture Content	Dry, Wet
2	Speed (m/min)	47, 71, 97
3	Feed rate (kg/h)	25

4. Results and Discussion

The performance of the thresher was evaluated at the various machine spindle speed, soybeans/stalks moisture content levels with an average feed rate of 25 kg/h. The separating efficiency, percentage breakage, and throughput capacity were calculated with equation 2, 3 and 4 respectively. Figure 3, 4 and 5 shows the results of the performance test.

4.1. Throughput Capacity

The throughput capacity ranged from 78.3 kg/hr to 96 kg/hr at a threshing speed of 47 to 71 m/min when tested with the dry mixture while it ranged from 45 kg/hr to 85 kg/hr when tested with wet mixture under the same variations. Figure 3 shows that the machine throughput capacity of 96 kg/hr yielded the best result at 71 m/min for the dry and wet mixture levels respectively. Though hypothetical, the throughput capacity should increase with an increase in machine shaft speed at the same repeated conditions, the results show otherwise. This was due to the manual design arrangements and spacing of the beaters to optimize the threshing efficiency at a moderate speed as results shown in figure 3.

4.2. Threshing Efficiency

The threshing efficiency of the machine ranged from 78.4% to 98.6% at a threshing speed of 47 to 71 m/min when tested with the dry mixture while it ranged from 48.3% to 68.4% when tested with wet mixture under the same variations. From figure 4, it shows that the threshing efficiency is significantly high at 71 m/min of machine speed for dry mixture. Therefore, it is recommended that the soya-beans stalks mixture be dried before threshing as the results closely follow that reported by [14].

4.3. Percentage Breakage

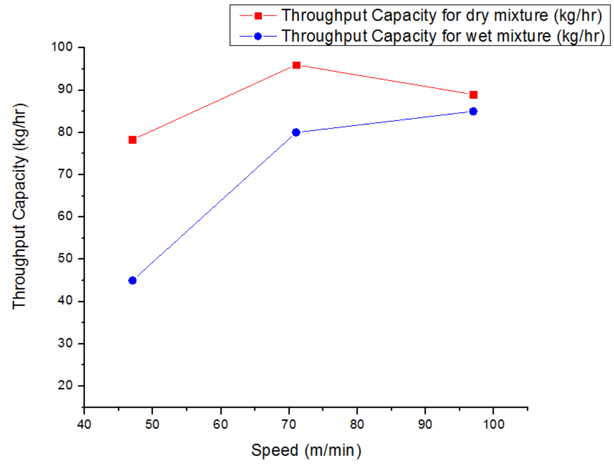

Figure 3. *Performance test of Throughput Capacity of the machine.*

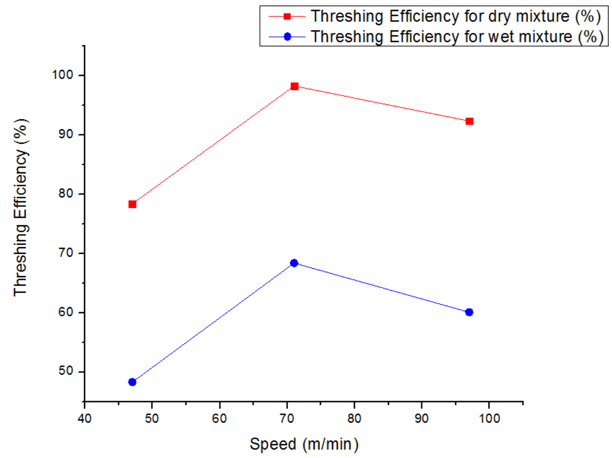

Figure 4. *Performance test of threshing efficiency of the machine.*

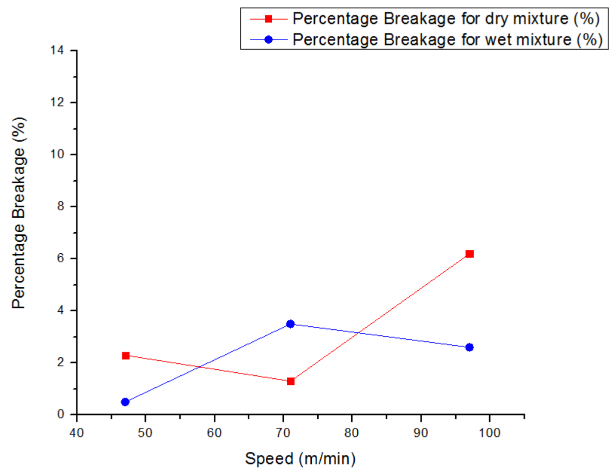

Figure 5. *Performance test of Percentage Breakage of the machine.*

The percentage breakage is the product of the weight of damage over the weight of damage plus the weight of undamaged grains. Figure 5 shows that the extent of percentage breakage was influenced significantly by the machine speed and moisture content of the sample mixture. The percentage breakage was least at 3.5% at 71 m/min of the machine speed when tested with the wet mixture while at 1.3% and at 71 m/min high when tested with dry mixture. As too wet mixture makes the grain moisture content high, is difficult to crack the grains and also results in trapped grains in the stalks while the dry sample mixture has less moisture content level which makes the grains brittle resulting in excessive grain damage at high speeds. This shows that, for optimal quality of grains, the threshing should be done when the mixture is moderately dry.

5. Conclusions

In conclusion, a soya-beans manual thresher was designed, fabricated and tested at Tamale Technical University, Northern Region Ghana. Based on the many test results, the performance of the machine was quite substantial. The design of the machine with local materials and manual transmission system was selected for cost effective and efficient operation of the machine and also in averting the frequent interruption of power supply in Ghana. The optimal performance of the machine was during the separation of the dry mixture which gave a throughput capacity of 96 kg/hr and threshing efficiency of 98.6%. This shows that the design of the thresher works best when the grain dried to the correct moisture content whereas wet moisture content leaves grain still attached to the stems and over dried moisture content leads to excessive grain damage. Therefore, with this performance, the machine will fill the gap between related traditional methods problems and highly sophisticated machines which are mostly scarce and inappropriate for use by rural farmers due to their high cost and maintenance problems. As such, this machine is recommended for the rural farmer to boost the production and processing of soybeans production in Ghana.

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