

Evaluation of a soybean threshing machine for small scale farmers

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Abstract: A soybean threshing machine was designed, fabricated and evaluated at Landmark University, Omu-Aran, Kwara State, Nigeria, to determine its performance and ease the drudgery problems associated with threshing of soybean by the small scale farmers. Evaluation was carried out with TGX 1448 soybean variety at different levels of moisture contents; 10%, 16% and 22% (wet basis) and at different drum speeds; 320 r/min, 385 r/min, 450 r/min, 515 r/min, with constant mass input of 600g and constant concave clearance of 23 mm. The overall mean results obtained for performance indicators in terms of threshing efficiency, cleaning efficiency, percentage of damage seed, percentage of blown seeds, percentage of seed loss and throughput capacity were 99.51%, 77.91%, 3.72%, 31.33%, 4.43%, and 35.44 kg/h, respectively. The evaluation results indicated threshing efficiencies of 98.96% to 99.88% for the range of the variable of drum speed between 320 r/min to 515 r/min and 99.73% to 99.29% for the range of the variable of moisture content of 10% - 22% (wet basis). The cleaning efficiency decreases (90.81% to 64.25%) as the speed increases (320 r/m into 515 r/min), at moisture contents of 10% and 22% (wet basis). The soybean threshing machine is simple to operate and maintain without formal education and the machine was fabricated from locally sourced materials. The unit cost of this threshing machine was ₦69,040.00, which is by far cheaper than imported soybean threshing machines.

Keywords: soybean, threshing, separation, efficiency, small scale farmers

Citation: Adekanye, T. A., A. B. Osakpamwan, and I. E. Osaivbie. 2016. Evaluation of a soybean threshing machine for small scale farmers. *Agricultural Engineering International: CIGR Journal*, 18 (2):426-434.

1 Introduction

According to FAO (2001) and Manuwa (2011), soybean is considered as one very important grain grown commercially in more than 35 countries of the world. Deshpande et al, (1993) concluded that soybean contains 40% protein, 35% total carbohydrate and 20% cholesterol-free oil. Smith and Circle (1972) opined that mineral content of whole soybean is about 1.7% of potassium, 0.3% of Magnesium, 110 ppm iron, 50 ppm zinc and 20 ppm copper. Soybean is the world leading vegetable oil and accounts for about 20% to 24% of all fats and oil in the world.

Soybean is becoming increasingly important in agriculture because it is a food source in human and animal nutrition. Soybean is among the major industrial and food crops grown in every continent. The crop can be successfully grown in many states in Nigeria using low agricultural input. Soybean cultivation in Nigeria has expanded as a result of its nutritive and economic importance and diverse domestic usage. It is also a prime source of vegetable oil in the international market. Soybean has an average protein content of 40% and is more protein-rich than any of the common vegetable or animal food sources found in Nigeria. Soybean seeds also contain about 20% of oil on a dry matter basis, and this is 85% unsaturated and cholesterol-free.

It is good for food-soy-milk, soy-cheese, *dadawa*, Tom Brown (infant weaning food); it is the source of an excellent vegetable oil, is used in industry, improves soil fertility and controls the parasitic weed,

Received date: 2016-01-08 **Accepted date:** 2016-04-03

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Strigahermonthica. Soybean cake is an excellent livestock feed, especially for poultry, the haulms provide good feed for sheep and goats.

Adekanye and Olaoye (2013) opined that the production of soybean is incomplete without threshing operation. Threshing involves the removal of grains from the pods. Threshing can be done either mechanically or manually. Manual system of threshing is characterized with time wastage, threshing losses, and high drudgery. Olaoye (2011) concluded that mechanical threshing involves high technology which is very expensive, though it helps to maintain the quality of the final products; it eliminates drudgery associated with local threshing system and reduces threshing losses. Threshing is a major post-harvest operation which is carried out after all crops have been gathered from the field. Threshing consists of separating the beans from the pods (portion of the plant fruit that encases the soybean seeds). Threshing as a post-harvest operation is as old as man. It can be done by hand using simple tools or motor-driven machines. Most soybeans are harvested and threshed simultaneously by modern combines. Whatever system used, it is very important that threshing be done with care to prevent breakage of the beans or hulls. According to NSRL (2010), careless threshing can reduce the quality of the products and foster subsequent losses from the action of insects and post-harvest diseases. The main objective of this study was therefore to design and fabricate a soybean threshing machine with locally available materials, evaluate the machine and determine its efficiency.

2 Machine descriptions

The soybean threshing machine was designed to be made up of the following major parts as is shown in Figure 1.

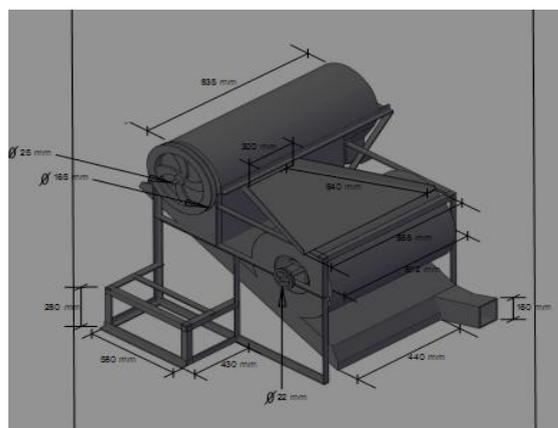


Figure1 Soybean threshing machine

Hopper: It is the part where the soybean pods are being fed into the threshing drum. It could also be referred to as the introductory section of the soybean pods into the threshing chamber. It is made of mild steel sheet and it's identified by a trapezoidal shape. It has a depth of 640 mm, width of 300 mm and length of 555 mm.

Threshing chamber: It is the part where the soybean seeds are beaten out of the panicles and separated first. It is made of mild steel sheet. It consists of a rotary drum (serrated type) to allow for the flow of soybean. This type of rotary drum was constructed due to the characteristics of soybean unlike other grains (e.g. maize which utilizes close drum threshing unit). The rotary drum is made of flat bar in serrated form with spike beaters fitted (properly welded) in the perforation on the flat bar. The threshing chamber also has a stationary screen which also acts as concave in the threshing machine (Figure 2).



Figure 2 Threshing chamber of soybean threshing machine consisting of spike tooth beaters, screen, disc bar, flat bar, shaft and bearings

Threshing unit: It is made of a central shaft, mild steel angle rod for the construction of flat bar, and mild steel rod for construction threshing spikes. It is a serrated spike tooth threshing drum type and it is housed inside the threshing chamber (Figure 3).



Figure 3 Fabricated soybean threshing machine coupled with a prime move

Screen: The screen is made with mild steel sheet with drilling of 11.5 mm bores (600 bores). It is concave in shape and perforated to allow for the threshed seed and chaff to pass through. It covers the lower portion of the threshing cylinder.

Fan assembly: It is made of mild steel material. It accommodates the blower blade and the shaft. The fan assembly consists of the primary and secondary fan assembly. The secondary fan assembly is at the axial end of the threshing chamber with three straight blades (165 mm × 135 mm). The primary fan assembly has four straight blades (510 mm × 120 mm). The primary fan assembly is located at a distance below the perforated screen. The fan assembly provides air current that aids the separation of seed and chaff.

Seed outlet: Also refers to the delivery chute. It is made of mild steel sheet. It was inclined to facilitate effective sliding of soybean grains considering the angle of repose of soybean seed. The opening is square in shape with dimension 160 mm.

2.1 Machine operation

A 6 hp diesel engine provides power to the threshing drum shaft which rotates with the help of bearings. The threshing drum provides drive to the shaft through belts and pulleys. In operation, the soybean panicles are fed into the threshing chamber through the hopper made of mild steel metal plate. The motorized thresher rubs the un-threshed soybean pods against metal concave. As the cylinder rotates, the soybean pod is forced through the gap between the concave (screen) and is subjected to impact and rubbing action that cause soybean pod and seed to be detached (shown in Figure 2). This machine operates on the principle of axial flow movement of material.

Threshing and pre-cleaning (seed/chaff separation) takes place within the threshing chamber which also consist of a secondary blower housing at axial end of the machine, the fan is also a centrifugal type and has two straight blades. The threshing unit consists of the threshing drum, 76.2 mm in diameter, the rod beaters arranged in spike form around the drum (24 rod spikes length 130 mm each). The beaters were 40 mm apart. The blower assembly consists of a primary fan which is centrifugal type and has four straight blades arranged to each other around the shaft at 120°. The blades are straight for effective cleaning of threshed soybean (i.e. removal of chaff from the seed). Threshed grains fall through the screen, while the light chaffs were conveyed to the axial end of the threshing chamber where they were thrown out from the secondary chaff outlet. Clean grains were collected through the seed outlet while the heavier particles were blown off from the fan assembly (primary chaff outlet).

2.2 Design analysis

The design analysis was carried out to determine the necessary design parameters, strength and size of materials required for various machine parts in order to avoid failure during operation of this machine.

2.2.1 Threshing drum diameter

Threshing drum diameter is required to determine the capacity of the soybean threshing machine. This was determined by using standard formula for calculating volume of a cylinder (see Equation 1 and Equation 2).

$$V = \frac{\pi d^2}{4} L \quad (1)$$

$$d = \sqrt{\frac{4V}{\pi L}} \quad (2)$$

Where; V = volume of the threshing drum, d = diameter of the cylinder (m), L = length of the cylinder (m)

2.2.2 Determination of pulley dimensions

The dimension of the pulley was determined using the following Equation 3:

$$N_1 D_1 = N_2 D_2 \quad (3)$$

Where; N_1 = speed of drive pulley, r/min; D_1 = diameter of drive pulley, m; N_2 = speed of thresher pulley, r/min; D_2 = diameter of thresher pulley, m.

2.2.3 Cylinder length

The cylinder length is determined from the following Equation 4 as reported by Kepner et al. (1978):

$$q = q_o l M \quad (4)$$

Where;

L = Drum length (m.);

q = Feed rate of thresher (kg/s); q_o

= Permissible feed rate(kg/s); M

= Number of (rows of) beaters.

2.2.4 Threshing velocity

Threshing velocity refers to the velocity of beaters which strike and rub the heads of soybean pod. Too high threshing velocity results in breaking or even shattering of the seed, thus rendering it unsuitable for use. Too low a threshing velocity causes insufficient separation of seed from the pod. The threshing velocity is expressed as Equation 5:

$$V_t = \frac{2\pi N r}{60} \quad (5)$$

Where; V_t = threshing velocity; r = radius of threshing drum,;

N = Speed of shaft in r/min

2.2.5 Force required for threshing soybean grain from the panicle

The threshing drum, which is attached to the shaft, rotates with the shaft, giving rise to centripetal force (F) (see Equation 6):

$$F = m\omega^2 r \quad (6)$$

Where; F = Centripetal force ; ; m = mass of thrshing bars, ; ω = angular velocity;

r = radius of the arm of the threshing drum..

Mass, m , of the threshing bars was determined by:

Mass (m) = density (ρ) \times volume (V)

Where; Volume (V) = length (L) \times breadth (B) \times thickness (t).

Determination of angular velocity, ω by Equation 7:

$$\omega = \frac{2\pi N}{60} \quad (7)$$

Where; N = Speed of shaft in r/min.

2.2.6 Shaft design – This 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. Design of shafts of ductile material based on strength is controlled by maximum shear theory. For a solid shaft having little or no axial loading, the ASME (1995) code equation is given as Equation 8:

$$d^3 = \left(\frac{16}{\pi S_s}\right) \times [(K_b M_b)^2 + (K_t M_t)^2]^{\frac{1}{2}} \quad (8)$$

Where; d = diameter of the shaft; M_t = torsional moment; M_b = bending moment;

K_b = combined shock and fatigue factor applied to bending moment; K_t = combined shock and fatigue factor applied to torsional moment; S_s = Allowable Stress.

2.2.7 Belt and pulley design

The total length of the belt was estimated to know the actual belt size required to transfer power from the prime mover to the threshing drum. Nominal pitch length (L) is given as by the Equation 9 given by:

$$L = 2C + 1.57(D - d) + \frac{(D - d)^2}{4C} \quad (9) \text{ (Gupta and Khurmi, 2005)}$$

Where; D = outside diameter of drive pulley (m), d = diameter of driven pulley (m),

C = distance between the centers of two pulleys

Belt speed

The belt speed was calculated using the Equation 10;

$$N = \frac{V}{\pi D} \quad (10) \text{ (Hannah and Stephen, 1984)}$$

Where; V = belt speed (m/s), N = drive speed (rpm), D = diameter of drive pulley (m)

2.3 Testing of machine

180 kg of soybean panicle were obtained from commercial farm of Landmark University, Omu Aran, Kwara State. The panicles were divided into nine samples and subjected to oven drying to obtain different moisture contents (10%, 16%, and 22% wet basis). An electronic digital moisture analyzer was used to determine moisture contents. The prime mover was initially run under no load condition using a 6 hp diesel engine to ascertain the smoothness of operation of rotating parts of the soybean threshing machine. The testing of the machine was carried out to determine threshing efficiency, cleaning efficiency and the percentage losses based on the moisture content of the seeds and the speed of the threshing drum. Performance test was conducted using 20 kg of soybean panicles of moisture contents (10%, 16%, and 22%) at (320 r/m, 385 r/m, 450 r/m and 515 r/m threshing speed. Each of the experiment was replicated three times.

2.3.1 Performance indicators

Threshing efficiency, cleaning efficiency, percentage of damage seed, percentage of blown seed, percentage of seed loss and throughput capacity were determined using Equations 11 - 15 (Mehta et. al., 1995; Sharma and Devnani, 1980; Bhutta *et al.*, 1997; Sessiz, 1998);

$$\text{Threshing efficiency } (\eta_{Thr}) = 100 - \left(\frac{W_{us}}{W_{ts}} \times 100 \right) \quad (11)$$

Where; η_{Thr} = threshing efficiency, W_{us} = weight of unthreshed seeds (g), W_{ts} = weight of total seeds (g)

$$\text{Cleaning efficiency } (\eta_{Cl}) = \frac{K}{W_G} \times 100 \quad (12)$$

Where; η_{Cl} = cleaning efficiency (%), K = weight of clean seed at seed outlet per unit time (g), W_G = weight of clean seed at all outlet (g)

$$\text{Percentage of damage seed } (Ds) = \left(\frac{W_{ds}}{W_{ts}} \right) \times 100 \quad (13)$$

Where; W_{ds} = Weight of damage seed at all outlets (g), W_{ts} = weight of total seeds (g)

$$\text{Percentage of blown seed } (Bs) = \frac{G}{A} \times 100 \quad (14)$$

Where; G = weight of clean seed collected at chaff outlet per unit time (g), A = weight of clean seed collected at seed outlet per unit time (g)

$$\text{Percentage of seed loss} = \left(\frac{W_{ds} + W_{us}}{W_{ts}} \right) \times 100 \quad (15)$$

Where; W_{ds} = weight of damage seeds, W_{us} = weight of unthreshed seeds, W_{ts} = weight of total seeds.

3 Results and Discussion

3.1 Threshing efficiency

Evaluation results indicated that the threshing efficiency was 98.96% to 99.88% for the range of the variable of speed between 320 r/min to 515 r/min and 99.73% to 99.29% for the range of the variable of moisture content level from 10% to 22% (wet basis). These trend shows that the effect of speed on the threshing efficiency was due to the high impact of the threshing drum on the soybean due to the increase in speed. Also threshing efficiency gradually increases as the speed increases (Figure 4). From Figure 5, it was observed that threshing efficiency gradually reduces as the moisture content increases irrespective of the increase in speed. This is an indication that at higher moisture

content, pod cohesion will be low. Threshing efficiency was highest (99.98%) at 515 r/min and moisture content

10% (w.b) respectively due to high impact and high pod cohesion force.

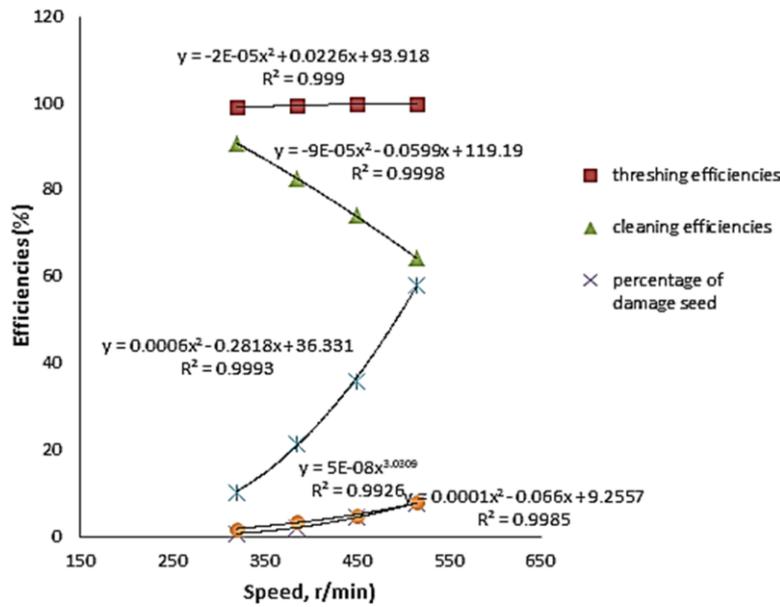


Figure 4 Effects of speed on threshing efficiencies, cleaning efficiencies, percentage of damage seed, percentage of blown seed, and percentage of seed loss on soybean

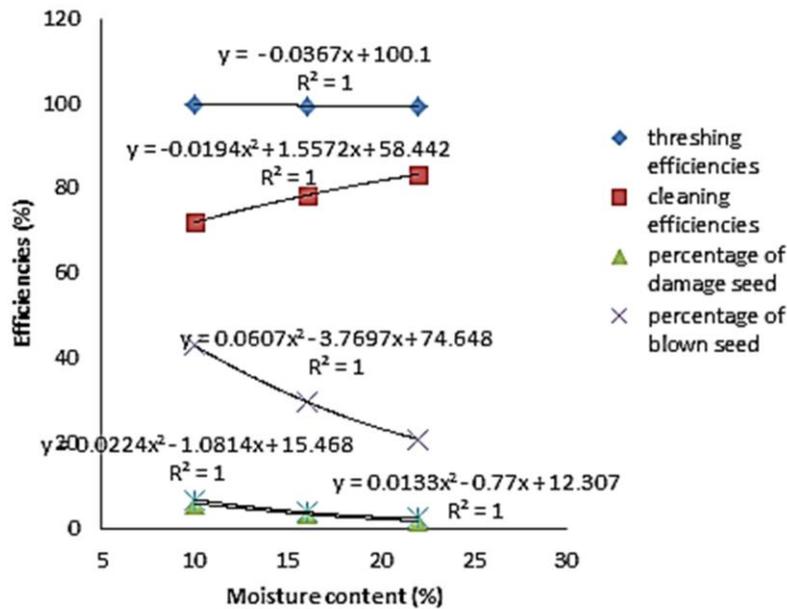


Figure 5 Effects of moisture content on threshing efficiencies, cleaning efficiencies, percentage of damage seed, percentage of blown seed, and percentage of seed loss

3.2 Cleaning efficiency

The cleaning efficiency ranges from 90.81% to 64.25% of the speed between 320 r/min to 515 r/min through moisture contents of 10% to 22% (wet basis). Figure 1 shows a declining trend in the cleaning efficiency with the effect of speed. This trend is as a

result of evaluation procedure of calculating the cleaning efficiency which is based on the ratio of the clean seed obtained from the main seed outlet to clean seed at the chaff outlet. From the test conducted more seeds were obtained at the chaff outlet as the speed increases from 320r/min to 515r/min. This new development occurred as

a result of the high air velocity of the fan assembly (possessing a higher terminal velocity to the soybean seed) which was also affected by the pulley size of the fan (small pulley size resulting to higher velocity).

This also led to the fact that at higher moisture content the cleaning efficiency increase gradually from 72.07% to 83.29% respectively as is shown in Figure 2 because of the increase in weight of seed due to higher water content in seed resulting to a greater terminal velocity in soybean seed which could not be easily blown by the air velocity of fan as in lower moisture content. This result is similar to the results obtained by Adekanye and Olaoye (2013) with respect to the effect of speed drum on cleaning efficiency.

3.3 Seed damage

Figure 4 shows the effect of drum speed on seed damage at different moisture contents and constant federates. The result indicated that the percentage of seed damage increased gradually with the increase in drum speed due to high impact and gradually reduced with the increase in moisture contents from 10% to 22% due to low seed cohesion and higher seed weight. This result compares well with the findings reported by Adekanye and Olaoye (2013) for cowpea thresher, Vejasit and Salokhe (2004) for soybean and Spokaset al. (2008) for wheat.

3.4 Blown seed

The same effect of the variables as in seed damage was observed in percentage of blown seed as is shown in Figure 4 and Figure 5, an increase in speed resulted to a rapid increase in blown seed and a rapid decline in blown seed as the moisture content increases.

3.5 Total seed loss

The total loss as spilled over and blown-up seeds ranged from a minimum of 1.78% to maximum of 7.85% for speed of 320 r/min to 515 rpm and ranges from a maximum of 6.89% to minimum 2.5% for moisture contents of 10% to 22% at a constant feed rate and concave clearance. At a lower speed and higher moisture content the total seed loss is at minimum range due to the low air velocity and high seed weight (Figure 4 and Figure 5). This trend agrees with the one reported by Ajav and Adejumo (2005) and Sudajan (2003) for okro and sunflower threshers respectively.

3.6 Throughput capacity

From Figure 6 it was observed that drum speed was proportional to throughput capacity. The highest throughput capacity (50.8) was obtained at the highest cylinder speed (515r/min) this trend compares well with the report obtained by Amadu (2012). Figure 7 shows the effect of moisture content on the throughput capacity, moisture content increased from 10% to 16% and then a rapid drop at 22%.

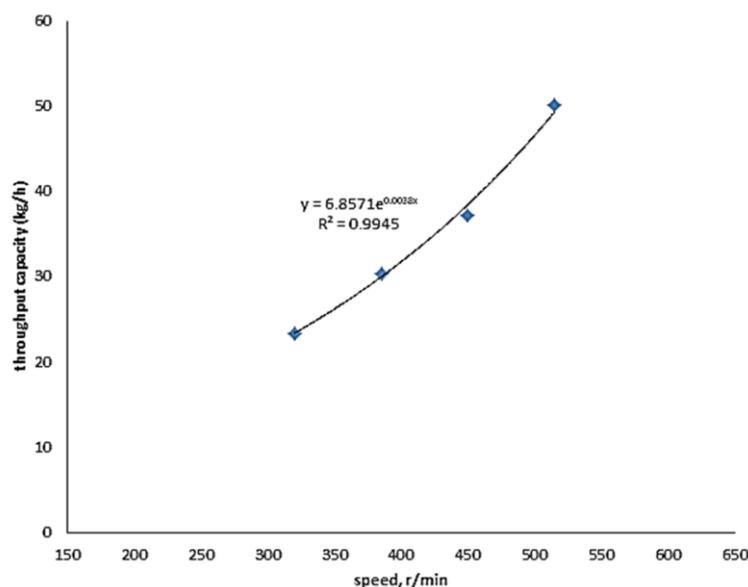


Figure 6 Effects of speed on throughput capacity

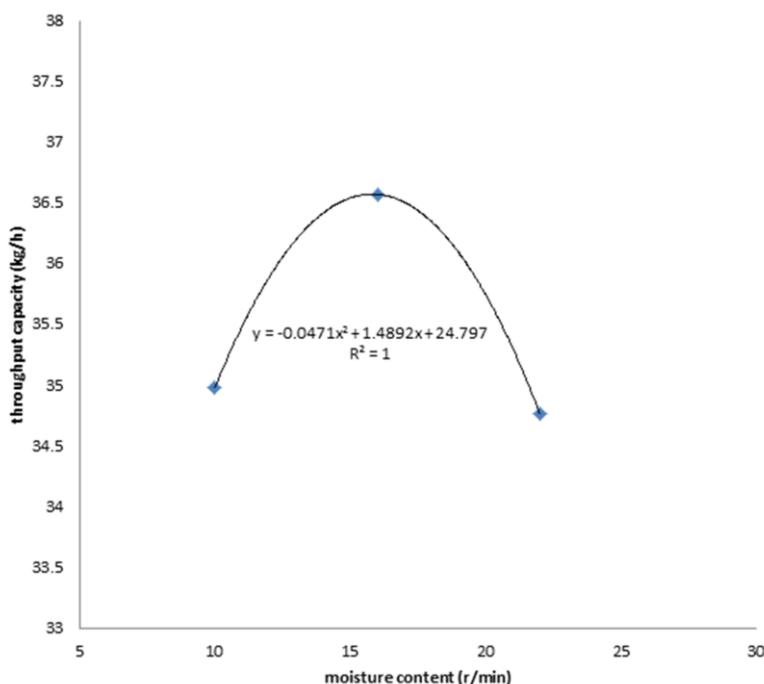


Figure 7 Effect of moisture content on throughput capacity

4 Conclusions

A soybean threshing machine was designed, fabricated and evaluated. It consists mainly of five parts: the feeding assembly, the threshing unit, fan assembly and power transmission unit. The thresher was evaluated using the TGX 1448 variety at different moisture contents (10%, 16% and 22% respectively). The performance evaluation revealed the following:

1. The overall mean threshing and cleaning efficiencies were 99.51% and 77.91% respectively.
2. The threshing efficiencies tend to increase with the increase in drum speed and decrease with the increase in moisture content while cleaning efficiencies increase as the cylinder speed decrease and as the moisture content increases.
3. High moisture content and low cylinder speed tend to reduce the percentage of damage seed, blown seed and seed loss respectively while low moisture content and high speed tends to increase the percentage of damage seed, blown seed and seed loss respectively. Moisture content state and impact on grain during

threshing are paramount in determining crop mechanical damage (Allen and Watts, 1997; Dauda, 2001).

4. The efficiency of the soybean threshing machine is significantly affected by the dependent variables, namely: cylinder speed and moisture content.

5. Spike tooth threshing drum tends to produce high threshing efficiency as seen from the results obtained (99.51%) which compares well with the report by Peksen et.al. (2013) for comparison of different beaters and concave for threshing chickpea.

6. The throughput capacity increases as speed increases. The soybean threshing machine has an overall mean throughput capacity of 35.44 kg/h.

7. The unit cost of the threshing machine was ₦69,040.00, which is by far cheaper and affordable for an average Nigeria farmer than imported threshing machines.

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