DEVELOPMENT OF AN IMPROVED SOYBEAN THRESHER

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ABSTRACT
Manual Soybean threshing is labour intensive and prone to wastage and contamination. A soyabean thresher was designed, constructed and tested. The effects of moisture levels (12.35, 16.52, 20.32, 23.78 and 26.96%) and machine speeds (900, 1200 and 1500 rpm) were investigated on threshing efficiency, cleaning efficiency, percentage grain loss, threshing recovery, throughput capacity, mechanical damage index and threshing performance index. The highest values of 99.60%, 90.80%, 97.70%, 70.38 kg/h and 92.34% were obtained for threshing efficiency, cleaning efficiency, threshing recovery, throughput capacity and threshing performance index, respectively. Whereas, the minimum values of 0.12% and 0.42% were obtained for percentage grain loss and mechanical damage index, respectively. At both 1200 rpm and 1500 rpm speeds, the throughput capacity increased as the moisture content increased up to moisture level of 24%. However, at speed of 900 rpm, the throughput capacity decreased as the moisture content increased. Hence, this thresher would help to ameliorate the stress usually experienced by farmers during manual threshing of soyabean and increase production, thus improving the economic standard of the producer.

KEYWORDS: Soybean, Thresher, Moisture content, Efficiency, Throughput

1. INTRODUCTION
Soybean is a legume that grows in tropical, subtropical and temperate climates. In 2016, the Global Soybean Production was about 313.02 million tons (Beliavskaya, 2017). All soybean varieties were confirmed to have high economic value and coefficient of agronomic stability higher than 70% (Beliavskaya, 2017). Animal husbandry is the largest consumer of soya protein and it is a growing industry around the world. Soybean is an excellent protein resource and also an efficient feed ingredient (Amadu, 2012). The Incorporation of soybean in Africa diet reduces the problem of malnutrition in African meal. It can also be used as condiment for production of moimoi and dadawa. Soybean oil is refined to produce paints, varnishes; Soap and sealant and for pharmaceutical use in vegetarian cooking and others such as soymilk (Merwe *et al*., 2013).

Adekanye and Olaoye (2013) highlighted that without threshing, soybean products could not be obtained. It was also pointed out that mechanical threshing is an expensive technology. Although, it helps to preserve the quality of the grains and eradicate the tedium and losses experienced with local threshing systems. An existing I.A.R soya bean thresher was modified and evaluated (Hyetson, 2003). The evaluation was done using TAS1485-ID variety of soybeans. It was found that the machine had 98 % threshing efficiency, 2.99 % mechanical grain damage, 75 % cleaning efficiency, 2.99 % scatter loss and 22 kg/ hr throughput capacity. Oforka (2004) also worked on an I.A.R soya bean thresher. With Samsoy- 2 variety at 10 % moisture content, the thresher had 96 % threshing efficiency, 2.86 % mechanical grain damage, 97 % cleaning efficiency and 2.86 % scatter loss.

Vejasit and Salokhe (2004) constructed a threshing unit to investigate the effects of machine-crop variables on the performance of an axial flow thresher for threshing soya beans. The outcome indicated that the threshing efficiency varied from 98% to100%. The grain damage and grain loss were less than 1% and 1.5% respectively. I.A.R (2006) tested an existing prototype soybean thresher for performance and found out that the threshing efficiency, cleaning efficiency, grain damage, scatter loss and output capacity obtained with Samsoy-2 variety were 80 %, 70 %, 2 %, 1.94 % and 23 kg/hr, respectively. While the values obtained with TAS 1485-ID variety were 86%, 64%, 1.6 %, 18%, 2.2 % and 21 kg/hr, respectively. Anurson and Vilas (2006) developed and evaluated an axial flow soya bean thresher. The threshing mechanism was a threshing drum rotating inside a two section concave. The most common soya bean variety KKU-35 grown in Thailand was used for the test. At grain moisture content of 14.34% (w.b), the throughput capacity, threshing efficiency and grain damage were found to be 214kg/hr, 99.49% and 0.80%, respectively.

Amadu (2012) also worked on an Improved I.A.R soya bean thresher and got threshing efficiency, cleaning efficiency, mechanical grain damage, scatter loss and throughput capacity to be 99 %, 95 %, 1.01 %, 2.7 % 2.7 % and 25.5 kg/hr respectively. However, the thresher had a problem of consistent chocking and loss of grains with the chaff during the threshing operations. Furthermore, most of these soybean threshers were evaluated without varying the moisture content of the grains which could have made the mechanical damage index values obtained to range between 1 and 3 %. Therefore, the objectives of the research were to develop an improved thresher for soyabean with provisions to prevent choking, recover of grains from the discharge chute and to vary the grain moisture content during its evaluation.

2. MATERIALS AND METHODS

2.1 Design considerations

For economical and efficient design of the soybean thresher, some factors were taken into consideration.

i) Due to high non-grain materials of soybean plant, a blower was attached to the threshing unit which could carry out removal of the straws at the threshing chamber. This was to prevent choking in the threshing chamber.
ii) Crop factors such as moisture content and angle of repose were also considered.
iii) Materials selection was based on the cost and availability of the materials without compromising their quality.

2.2 Design of the Soybean Thresher

A solid circular cross-section shaft was designed using the relationship in Equation (1) given by Philip *et al*. (2017):

$$d^3 = \frac{16}{\pi S_S}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (1)$$

where:

d = Shaft diameter (m)
M_b = bending moment on shaft (Nm), M_t = torsional moment on shaft (Nm)
K_b = combined and fatigue factor applied to bending moment = 1.5
K_t = combined and fatigue factor applied to torsional moment = 1.0
S_s = Allowable shear stress for steel $1.2 \times 10^8 \mathrm{N/m^2}$ (ASME code)

The shaft diameter value obtained was 33.6 mm.

In the pulley diameter determination, the expression in Equation (2) established by Sanjay (2010) was used:

$$N_1 d_1 = N_2 d_2 \tag{2}$$

where:

N_1= Speed of driving pulley (rpm),
d_1 = diameter of driving pulley (m),
N_2 = Speed of driven pulley (rpm),
d_2 = diameter of driven pulley (m)

An open drive vee belt was designed for the machine. The length was calculated using the relationship in Equation (3) given by Fadele and Aremu (2016):

$$L = \frac{\pi}{2}(d_2 + d_1) + 2x + \frac{(d_2 - d_1)^2}{4x} \tag{3}$$

where:

L = Length of belt (mm),
x = distance between the centres of driving and the driven pulleys (mm),
d_1 and d_2 are as earlier defined.

2.3 Description of the Soybean Thresher

The soybean thresher consists of hopper, threshing cylinder, blowers, chaff outlets and other components. The exploded isometric view of the soybean thresher is shown in Figure 1. Likewise, the orthographic views of the thresher are shown in Figure 2.

Hopper: It is the part where the soybean pods were fed into the threshing chamber. It has trapezoidal cross section. It makes an angle of 45° to the horizontal in order to take care of the angle of repose of soybean on mild steel.

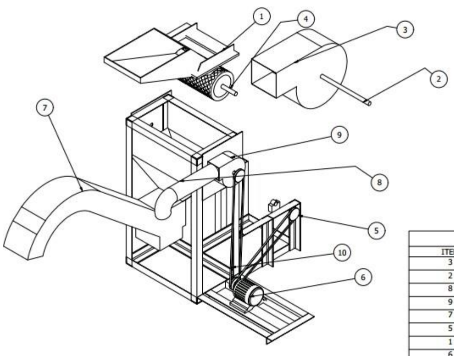
Threshing Cylinder: Threshing cylinder and concave together makes the threshing chamber. Four rows of spikes were arranged on the threshing cylinder while two rows of spikes were arranged on either side of the concave. Rotation of the threshing cylinder inside the stationary concave brings about the threshing of the soybean pods. The threshed soybean grains and some chaff pass through the hole on the concave.

Blower: One blower was attached to the left side of the threshing chamber in order to suck out chaff and prevent choking in the threshing chamber. The other blower was placed beneath the concave to blow away chaff from the mixture of grains and chaff coming out of the concave. These blowers assist in proper separation of grains from chaff.

Chaff Chute: This is the outlet through which the chaff is thrown out of the thresher. It was curved downwards at the tip to allow for easy collection of the chaff with a container. By this, it is possible to inspect the chaff for grains and pick them out if necessary.

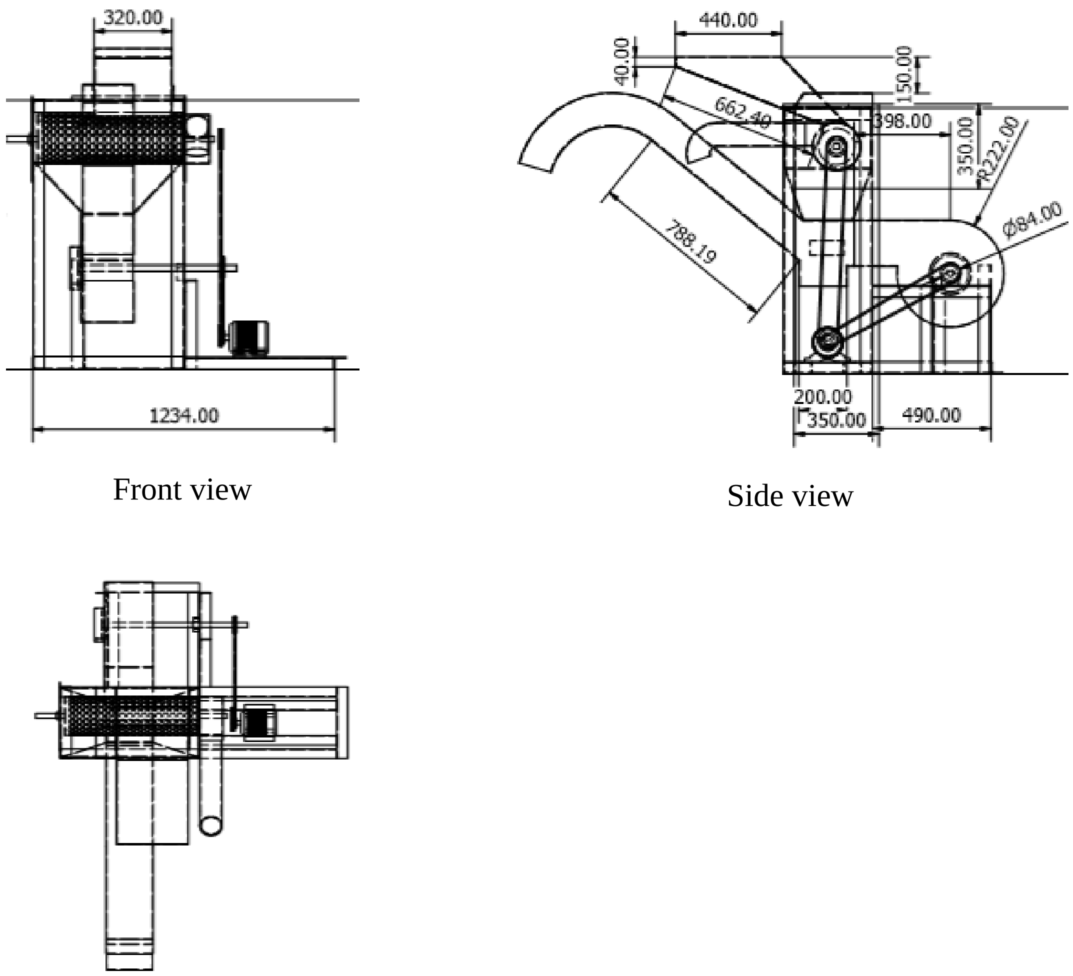
2.3 Mode of Operation of the Soybean Thresher

The mature dry soybean pods are fed through the hopper from where they flow by gravity into the threshing chamber. The grains are detached from the pods by the rotation of the threshing drum against the stationary concave. Some chaff will be drawn and blown out by the fan attached to the threshing drum. Mixture of grains and chaff pass through the openings on the concave. Another blower below the threshing drum does the final cleaning of the grains. The grains are being collected at the grain outlet while the remaining chaff is blown out through the chaff chute. A picture of the fabricated Soybean thresher is shown in Figure 3.



PARTS LIST	
ITEM	PART NUMBER
3	BLOWER
2	Blower shaft
8	Chaff Chute
9	fan
7	Grain Chute
5	Grooved Pulley2
1	Hopper
6	MOTOR
4	Threshing Cylinder
10	V-Belt

Figure 1: Exploded isometric view of the Soybean thresher



Plan

All dimensions in mm

Figure 2: Orthographic views of the Soybean thresher

Figure 3: The fabricated Soybean thresher

2.4 Sample Preparation

Soybean variety used was TGX 1448-2E. Sample selection was randomized all through the tests and care was taken to ensure that only good seeds were used. The moisture content of the sample was determined by using grain moisture analyzer. The initial moisture content of the soybean was 12.35%, three replicates of the sample were threshed at 12.35% moisture content, and each sample weighed 800g. Manual decortications of pods of soya bean was done in three replicates, this was used to establish the average seed to chaff ratio, which was found to be 0.125. The soybean was conditioned by adding a calculated quantity of water, which was mixed thoroughly in the samples and sealed in separate polyethylene bags to get the other moisture content levels. The relationship in Equation (4) given by Adejumo and Abayomi, (2012) was employed. The samples were kept in a cool place for some period of time in order to have uniform distribution of moisture throughout (Adejumo and Abayomi, 2012).

$$Q = W_i \frac{(M_f - M_i)}{(100 - M_i)} \qquad (4)$$

where:

Q = the quantity of water added (kg);
W_i = initial weight of sample (kg);
M_i = the initial moisture content of sample (%) dry basis
M_f = the final moisture content of sample (%) dry basis

2.5 Performance Evaluation of the Soybean thresher

The Soyabean thresher was tested using the performance indices: Threshing efficiency, Cleaning efficiency, Percentage grain loss, Threshing recovery, Throughput capacity, Mechanical damage index and Threshing performance index. The soybean to be threshed was conditioned to five (5) desired moisture contents (12.35, 16.52, 20.32, 23.78 and 26.96 %). The speed of the thresher was varied and set as (900, 1200 and 1500 rpm) by the use of a frequency inverter. The following expressions in Equations (5) to (11) obtained from NSAE/NCAM/SON (1997) were employed

(i) Threshing Efficiency

The threshing efficiency is determined by

$$E_T = \left(1 - \frac{D}{A}\right) \times 100\% \qquad (5)$$

where:

E_T = Threshing efficiency (%)
D = Weight of unthreshed seeds at all outlet per unit time (kg)
A = Total seed input per unit time (kg)

(ii) Cleaning Efficiency

$$E_C = \left(1 - \frac{q \times G}{A}\right) \times 100\% \qquad (6)$$

where:

E_C = Cleaning efficiency (%)
q = seed/straw ratio
G = weight of chaff-in seed outlet per unit time (kg)
A = Total seed input per unit time (kg)

(iii) Percentage Grain loss

$$P_{GL} = \left(\frac{H}{A} \times 100\right)\% \qquad (7)$$

where:

P_{GL} = percentage grain loss (%)
H = weight of all seeds (whole damaged and unthreshed) at chaff outlet per unit time (kg)
A = Total seed input per unit time (kg)

(iv) Threshing Recovery

$$T_R = \left(\frac{B}{A} \times 100\right)\% \qquad (8)$$

where:

T_R = threshing recovery (%)
B = weight of threshed seeds at the main outlet per unit time (kg)
A = Total seed input per unit time (kg)

(v) Throughput Capacity

$$C_{TH} = \left(\frac{B}{T_1} \times 60\right) \qquad (9)$$

where|:

C_{TH} = capacity throughput (kg/hr)
B = weight of threshed seeds at the main outlet per unit time (kg)
T_1 = time of test-run (hr)

(vi) Mechanical Damage Index

$$E_D = \left(\frac{E}{A} \times 100\right)\% \qquad (10)$$

where:

E_D = machine damage index (%)
E = weight of damaged seeds collected at all outlets per unit time (kg)
A = Total seed input per unit time (kg)

(vii) Threshing Performance Index

$$TPI = 100E_C \times E_T\ (1 - E_D) \qquad (11)$$

where:

TPI = threshing performance index
E_C = Cleaning efficiency (in decimal)
E_T = Threshing efficiency (in decimal)
E_D = Mechanical damage index (in decimal)

3. RESULTS AND DISCUSSIONS

The results of the performance evaluation of the thresher are presented based on the variations of the performance indices to the five levels of moisture content at each selected thresher speed.

3.1 Effect of Moisture Content and Speed on Threshing Efficiency

Figure 4 indicates the effects of the moisture content and speed on threshing efficiency. It could be seen that highest threshing efficiency of 99.60% was at moisture level of 20 % and speed of 1500 rpm. The least threshing efficiency of 97.70 % was obtained at moisture content of 16 % and speed of 900 rpm. According to Adekanye *et al*. (2016) the threshing efficiency increases for every range of variable of speed, it was stated that the threshing efficiency of their Soyabean thresher increased from 98.96 % to 99.88% at speed range of 320 rpm to 515 rpm.

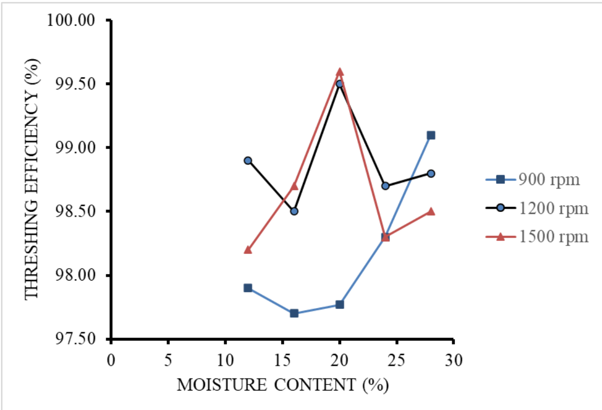


Figure 4: Variation of moisture content and speed on threshing efficiency

3.2 Effect of Moisture Content and Speed on Cleaning Efficiency

Figure 5 depicts the effects of the moisture content and speed on cleaning efficiency. At the speed of 1200 rpm and moisture level of 24%, the highest cleaning efficiency value of 90.80% was observed. The cleaning efficiency increased from 16 % moisture content up to 24% moisture content after which it declined. From the figure, as the machine speed increased, the cleaning efficiency also increased. This study is similar to that of Adekanye *et al*. (2016) in which the cleaning efficiency dropped drastically from 90.81% to 64.25% as the speed and moisture content increased.

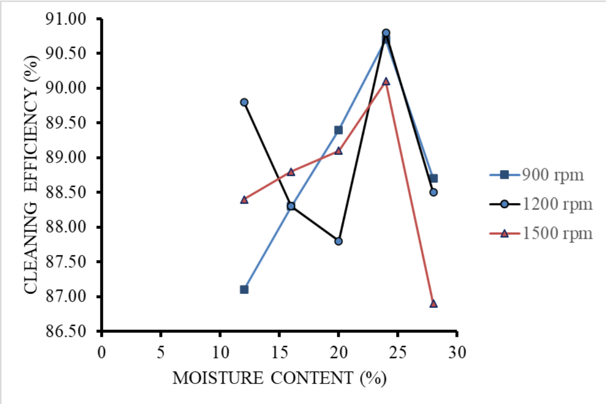


Figure 5. Variation of moisture content and speed on cleaning efficiency

3.3 Effect of Moisture Content and Speed on Percentage Grain Loss

The effects of the moisture content and speed on percentage grain loss is shown in Figure 6. The highest percentage grain loss of 0.59% was at speed 900 rpm and moisture content value of 24%. The percentage grain loss generally decreased as the moisture level increased from 12 to 28%. At 1200 rpm there was no sharp changes in the values of percentage grain loss. This could be due to the fact the speed of 1200 rpm was appropriate for minimal grain loss. At 1500 rpm, percentage grain loss declined steadily. The results obtained are in conformity with those of Amadu (2012) for Soybean thresher.

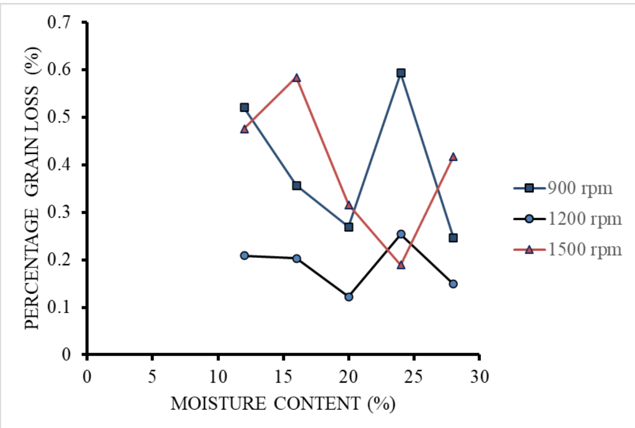


Figure 6. Variation of moisture content and speed on percentage grain loss

3.4 Effect of Moisture Content and Speed on Threshing Recovery

Figure 7 depicts the effects of the moisture content and speed on Threshing recovery. The threshing recovery was lower at 900 rpm when compared to the other machine speeds. Threshing recovery increased as the moisture content increased at all speeds. However, after moisture level of 20%, it began to drop at all speeds. The highest threshing recovery value of 97.70% was obtained at speed of

1200 rpm and 20% moisture content level. This is in concordance with the results obtained by Philip *et al*. (2017) for Soybean thresher.

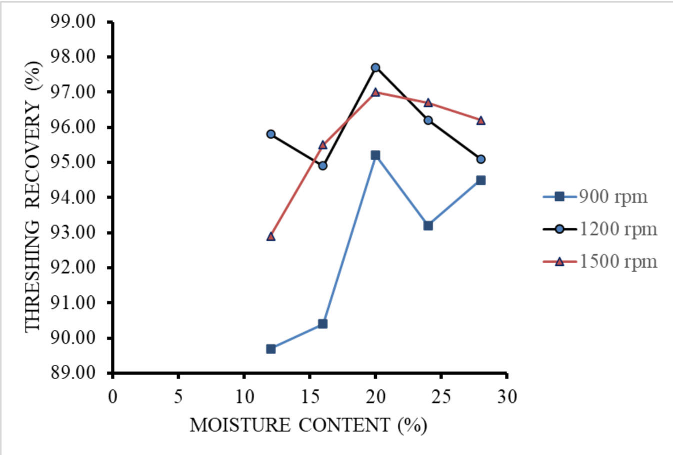


Figure 7: Variation of moisture content and speed on threshing recovery

3.5 Effect of Moisture Content and Speed on Throughput Capacity

The effects of moisture content and speed on Throughput capacity are shown in Figure 8. The highest Throughput capacity of 70.38 kg/h was obtained at speed of 1500 rpm and moisture level of 16%. The both 1200 rpm and 1500 rpm speeds, the Throughput capacity increased as the moisture content increased up to moisture level of 24%. However, at speed of 900 rpm, the Throughput capacity decreased as the moisture content increased. These results obtained here are in line with the observations made by Adekanye *et al*. (2016) for Soybean thresher.

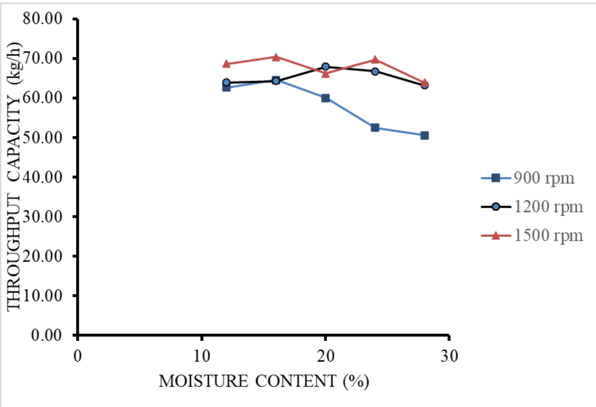


Figure 8: Variation of moisture content and speed on throughput capacity

3.6 Effect of Moisture Content and Speed on Mechanical Damage Index

Figure 9 depicts the effects of the moisture content and speed on Mechanical damage index. The mechanical damage index was high at 900 rpm as compared to the two other speeds. The least value of 0.42% mechanical damage index was obtained at 1500 rpm. At the speeds of 1200 rpm and 1500 rpm the mechanical damage index was minimal at moisture level of 20%. This is similar to the observation by Amadu (2012) for Soybean thresher.

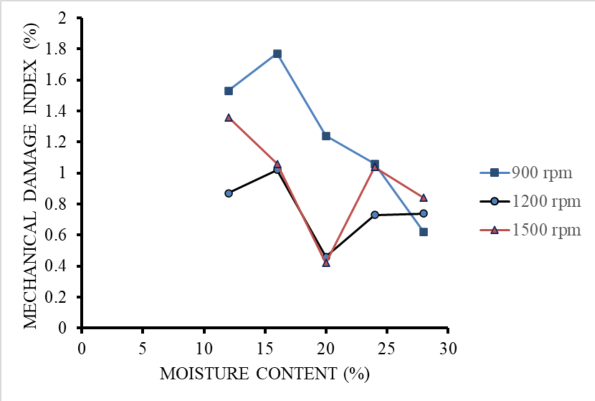


Figure 9: Variation of moisture content and speed on mechanical damage index

3.7 Effect of Moisture Content and Speed on Threshing Performance Index

The effects of moisture content and speed on threshing performance index are shown in figure 10. At 900 rpm speed and moisture level of 12%, the least threshing performance index of 74.25% was obtained. The threshing performance index was highest (92.34%) at speed of 1500 rpm and moisture level of 20%. At speeds of 900 rpm and 1200 rpm the threshing performance index were relatively stable between moisture levels of 16 and 28%. Similar trend was obtained by Amadu (2012) for Soybean thresher.

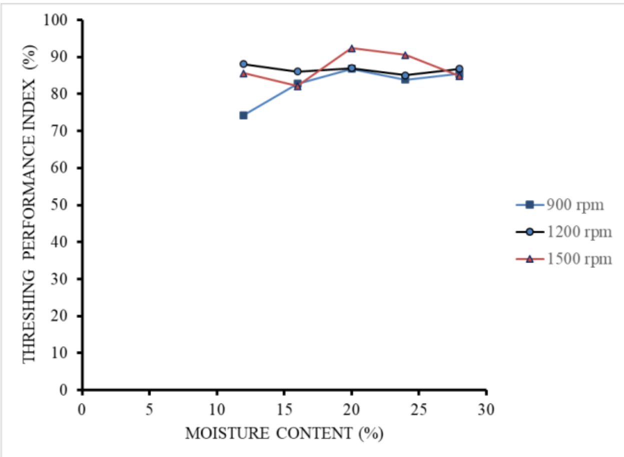


Figure 10: Variation of moisture content and speed on threshing performance index

4. CONCLUSION

A soya bean thresher was designed, fabricated and evaluated. It consists mainly hopper, threshing cylinder, blowers, chaff outlets and other components. The highest performances of the machine were obtained as 99.60% for threshing efficiency, 90.80% for cleaning efficiency, 70.38 kg/h for throughput capacity and 92.34% for threshing performance index. The least values of percentage grain loss and mechanical damage index were 0.12% and 0.42%, respectively. At both 1200 rpm and 1500 rpm speeds, the throughput capacity increased as the moisture content increased up to moisture level of 24%. However, at speed of 900 rpm, the throughput capacity decreased as the moisture content increased. Hence, this improved soybean thresher is recommended for the rural farmers to boost their production and processing of soybean which will in turn improve the economic status.

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