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Performance Evaluation of a Motorized Legume Threshing Machine

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ABSTRACT

Grain threshing and separation are important post-harvest unit processes because they reduce excessive wastage and add value to farm produce, amongst other benefits, thus, the performance parameters of the legume threshing machine were determined experimentally. The effect of the static coefficient of friction on the Threshing Efficiency (TE), Separation Efficiency (SE), Grain damage and Machine throughput was determined. The study was carried out using a randomized design of three feed rates (FR): 10g/s, 15g/s and 20g/s, four surfaces (S) mild steel (MSTEEL), plywood (PLYWD), carpet (CARPT) and Rug (RUG) using cowpea (Vigna unguiculata) IT84S-2242 and soybean (Glycine max L) 1448-2E variety. The cleaning efficiency obtained for soybean samples was 96%, while the threshing efficiency was 97.4%. For cowpea, threshing and cleaning efficiencies were 97.44 and 97.16%, for carpet surface. Statistical analysis using ANOVA showed that impurity level and feed rate affected cleaning efficiency at both 1 and 5% significance, and type of surface affected threshing percentage and broken seeds at 5% significance. Using carpet surfaces resulted in the highest cleaning efficiency, threshing efficiency, low grain damage and grain losses at 100 g batch weight. In conclusion, the coefficient of friction could be utilized to increase the separation efficiency of the thresher, this would aid the development of appropriate technologies for legume processing.

INTRODUCTION

The global human population explosion has placed an increased demand on agricultural productivity and food supply, which in turn has caused agricultural mechanization to become an indispensable process (Wamalwa *et al*. 2022). The use of agricultural machinery increased annual global grain production to 2.5 billion tons, reduced excessive wastage of agricultural produce, and allowed for efficient performance of farm operations (Irtwange, 2009).

One of the widely cultivated legumes is cowpea, it is widely distributed throughout the tropics and sub-tropics and is grown throughout the lowland tropics of Africa (Faleye *et al*. 2013). Nigeria currently cultivates about 40 million ha of cowpea and produces an estimated 850,000 tons annually (Faleye *et al.* 2013). The chaff is fed to livestock, while the seeds are consumed or sold after being dried to 8-10% moisture content (Olaoye, 2011). Soybean is also considered a very important grain grown commercially in more than 35 countries of the world; its total worldwide production is about 180 million tons per year, making it the world's most produced and internationally traded leguminous plant (Harerimana *et al.* 2024).

The post-harvest processing of these legumes into animal and human food poses enormous challenges, therefore threshing operation is considered a foremost important post-harvest operation and is carried out to remove grains from the plant residues (Ajit *et al.* 2006), it results in the separation of impurities and contaminants from sound grains, thus reducing the problems of storage and handling (Wamalwa *et al*. 2022)

Once threshing is accomplished separation process usually follows. In most equipment, both processes are performed sequentially in the same machine, while some equipment threshes separately with cleaning carried out manually later (Ajit *et al.* 2006). Mechanization of cleaning operations is important because it saves effort, reduces operation time and reduces crop losses (Ajit *et al*. 2006). During grain cleaning, the aerodynamic properties of crops such as terminal velocity and drag coefficient are employed to separate and remove chaff and other debris such as foreign materials, broken kernels and splits from grains so that desirable products are separated from unwanted materials (Zewdie 2024; Vasundhara *et al.* 2019).

The application of static Coefficient of Friction (COF) as a physical property was exploited in a cocoa husk separator to separate a mixture of cocoa beans and husks by sliding test samples on an inclined plane covered with rubber or carpet made from a mixture of polystreylene and polypropylene (Owolarafe *et al.* 2007). The results obtained showed separation efficiency was 50-86% at an angle of inclination of 35°, the separation efficiency at 25° was 80-99%, while at an angle of inclination of 20°, the separation efficiency obtained was 74-97%. The results show that separation efficiency increases with a reduction in the angle, this is because at smaller angles of inclinations, the force of inertia slowing material movement is larger compared to the force of gravity causing bulk flow, so that the different components in the materials move at different rates, but as the angles are increased, the force of gravity is larger and quick bulk flow of materials occurs (Owolarafe *et al.* 2007). Some values of the COF of soybean on different surfaces are 0.22 - 0.30 (glass), and 0.33 - 0.42 (plywood) (Davies and El-Okene 2009). The COF for three varieties of cowpea at 15 - 30% moisture content are: 0.26-0.43 (glass surface) 0.30-0.60 (plywood surface) IAR-339-1 variety, 0.30-0.51 (glass surface), 0.34-0.61 (plywood surface) IT86D-1010 variety and 0.24-0.45 (glass surface,), 0.36-0.58 plywood surface) Ife Brown variety (Davies and Zibokere 2011). Kayode and Bayode (2019) obtained the COF for soybean on wood, mild steel and glass surfaces as: 0.22 (wood), 0.37 (mild steel) and 0.19 (glass), while for cowpea COF was: 0.28 (wood), 0.27 (mild steel) and, 0.24 (glass). High COF values imply that the crop fraction experiences more friction and has retardation to flow on that surface, while COF implies a lesser impediment to crop fraction flow.

This study redesigned a motorized thresher to incorporate different separation surfaces, evaluation tests were carried out to determine the performance of the modified legume thresher considering feed rate and level of impurity so that the best combination of parameters for achieving optimal separation efficiency could be determined.

The Modification to Incorporate COF Surfaces in the Machine

Ige (1978) designed and fabricated the cowpea thresher, which was modified and redesigned as a multi-crop thresher for handling legumes. The modification involved incorporating an inclined surface and a centrifugal fan so that a higher amount of stems, stalks, foreign materials and impurities that soybean is harvested with can be handled. This inclined trough was attached beneath the threshing chamber, it was lined with strips of each COF material sequentially. threshed materials consisting of grains and impurities collected and flowed over the inclined COF surfaces, then were discharged into a suitably attached blower.

METHODOLOGY

The AUTOCAD 3D isometric and orthographic drawings of the modified thresher are shown in Figures 1 and 2, respectively. The trough was shaped like a chute, its base rectangular dimension was 25 × 75 cm and it was made of a 1.5 mm thick mild steel inclined at an angle of 25-30° from the vertical and a height fall of 90 mm. Four different materials, mild steel (MSTEEL), plywood (PLYWD), rug (RUG) and carpet (CARPT) at angles of inclination 25°, 29°, 27°and 28° respectively were utilized in the study (Owolarafe *et al.* 2007). Mild steel and Plywood are hard surfaces, they were chosen so that grains can rebound quickly on them, while chaff moves slowly relatively. Also, Rug and Carpet should impede the irregularly shaped chaff compared to the more spherical grains. The materials from the inclined trough were then passed into a centrifugal fan for final separation. Threshed materials from each experimental run were carefully collected and labeled for analysis. Each treatment was replicated thrice for Soybean and twice for Cowpea. Three feed rates were also considered in a randomized complete block design (RCBD).

Performance evaluation of the modified threshing machine

The moisture content (wet basis) of the soybean grain from the oven drying method was 7.63% and the cowpea moisture content was 11.43%. Using the digital anemometer, the exit air velocity at the blower was 7.5 – 10.0 m/s, while the inlet air velocity was 1.0 – 2.0 m/s. The blower shaft speed was between 1350 – 1550 rpm for the blower shaft and 800 – 900 rpm for the threshing shaft to avoid grain damage during threshing and wastage losses during separation. The COF of the cowpea variety on the four surfaces are: 0.22-0.35 (PLYWD), 0.37-0.40 (CARPT), 0.33-0.35 (RUG), 0.17-0.28 (MSTEEL). The evaluation was carried out using a completely randomized design. Three feed rates: 10, 15 and 20 g/s of two legume cowpea (*Vigna unguiculata*) and soybean (*Glycine max* **L**.) were used. To avoid material clogging in the threshing drum, the samples of batch weight (100g, 150g and 200g) were fed over 10 seconds. The seeds were collected from the Osun State Agricultural Development Programme (OSADEP), Iwo, Osun State, and a private farm in Saki, Oyo State, South West Nigeria. The machine performance evaluation parameters are:

Threshing efficiency (TE): is the amount of threshed grains in the collected materials from the discharge outlet, it is expressed as:

$$TE = \frac{M_t}{M_u + M_t} \times 100\% \qquad (1)$$

where TE is the threshing efficiency (%), M_t is the mass of threshed grains (g) and M_u is the mass of unthreshed grains (g). (Devesh *et al*. 2016, Choszcz *et al*. 2020)

Cleaning efficiency (CE) is the mass of impurities separated from the seed mixture from all impurities in the seed mixture; it is the effectiveness of the threshing machine in separating chaff from grain kernels. It is given as (Harerimana *et al*. 2024; Devesh *et al*. 2016; Choszcz *et al*. 2020):

$$CE = \frac{W_t - W_c}{W_t} \times 100\% \qquad (2)$$

where W_t is the total weight of the mixture of grain and chaff received at the grain outlet, and W_c is the weight of chaff at the chaff outlet of the thresher (g).

Percentage loss (PL) is the quantity of seed collected on the approach tarpaulin compared to those from the discharge outlets and is expressed (Dangora *et al*. 2024; Devesh *et al*. 2016) as

$$PL = \frac{M_l}{M_r + M_l} \times 100\% \qquad (3)$$

where PL is the percentage loss (%), M_r is the mass of recovered seed (g) and M_l is the mass of seed losses (unthreshed loss + separation loss scattering + blower loss) (g).

Grain throughput capacity (T): This is the capacity of the thresher in terms of the total quantity of threshed materials in samples per hour, which is expressed as equation 4 (Qabaradin and Tsegaye, 2021):

$$T = \frac{Q}{t} \times 100\% \qquad (4)$$

Where *Q* is the quantity of threshed grain collected after a threshing operation (kg) and *t* is the time taken for a complete threshing operation (h).

RESULTS AND DISCUSSIONS

Threshing efficiency of the machine for cowpea samples

The effects of feed rate and COF on the TE of the legume threshing machine for cowpeas are shown in Figure 3. From the figure, as the feed rate is varied for MSTEEL, CARPT and PLYWD surfaces, a parabolic response in the TE is obtained, with the maximum TE occurring at FR2 (150g/batch), but for the MS surface, the least TE value was obtained at FR2. The increased values of TE obtained in CARPT can be attributed to the combination of grain rebound and the material surface impeding the movement of irregular-shaped chaff materials. On the MSTEEL surface, the TE obtained is less than that from CARPT, because although MSTEEL provides rebound to grains, it does not impede the relative movement of chaff and grains. The values obtained for TE at the least feed rate (FR1) are: 91.5% (MSTEEL), 96.1% (CARPT), 94.2% (RUG) and 94.4% (PLYWD) while the least TE values obtained were 88.7% (FR1, MSTEEL), 90.5% (FR2, MSTEEL) and 91.8% (FR3 RUG). Olaoye (2011) reported that TE increased from 97.8 to 99.8% as threshing speed increased from 7.95 to 13.92 m/s. Harerimana *et al*. (2024) reported that TE reduced from 100.0 to 98.0% as the feed rate was increased from 1 to 4 kg/min.

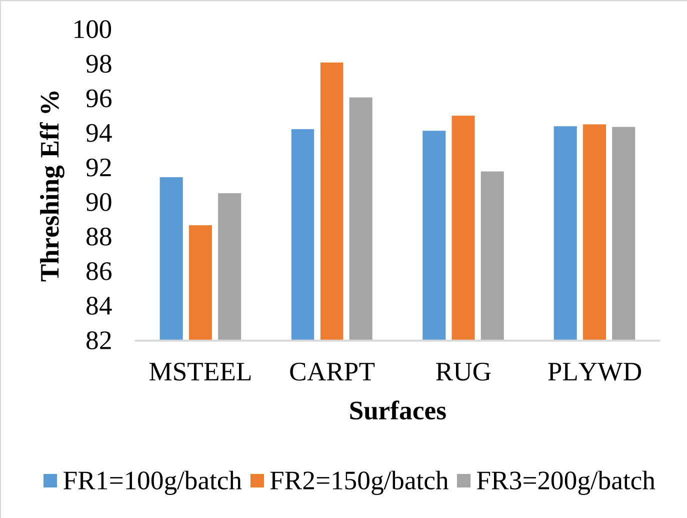

Figure 3: Threshing efficiency of cowpea for various surfaces.

Increasing the feed rate resulted in a reduction of grain TE and MS had the lowest values of TE. Osueke (2013) explained the reduction in threshing efficiency as the feed rate is increased as follows: at a high feed rate, grain kernels take a longer time to travel through the mat formed by threshed material in the threshing drum, slowing the threshing rate. Osueke (2013) employed the concept of energy balance expressed by Eqn. 5:

$$Ei = Eabc + Eabs + E_r \qquad (5)$$

Where i is the impact, abc is absorbed by the cushion, abs is absorbed by the specimen, and r is a rebound. The equation shows that at low feed rates, most of the energy available at the threshing drum is expended on removing grains from stalks and husk, but as the feed rate increases, grain clustering occurs, which reduces the energy absorbed by grains and their rebound energy, because cushioning materials absorb more energy. The reduction in energy to separate grains from stalks causes more unthreshed grains at the end of the threshing operation.

Threshing efficiency of the machine for Soybean samples

The effects of feed rate and COF on the TE of the legume threshing machine for soybean is shown in Figure 4, it shows that TE reduces as feed rate is increased, the TE obtained is 97% (FR1, CARPT) and 99% (FR1, PLYWD), while the least values are 87% (FR3, MS) and 89% (FR3, PLYWD).

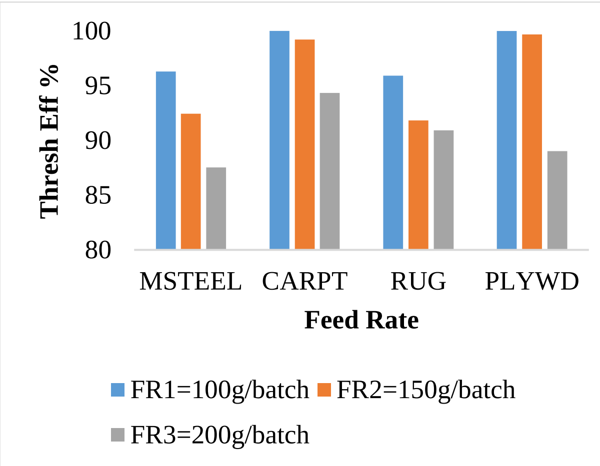

Figure 4: Threshing efficiency of Soybean for various surfaces.

The TE pattern of the soybean experiment is similar to that of the cowpea experiment, where the highest TE came from CARPT and PLYWD which combined both grain rebound and chaff retardation. The results show that the amount of broken seed increases with an increase in feed rate. The percentage of broken grains is between 0.00 and 0.78% for plywood and carpet surfaces at 100 g batch weight and 200 g batch weight, respectively. The percentages are 5.7, 9.1, 10.9 and 12.5% at 200 g batch weight for CARPT, RUG, PLYWD and MSTEEL surface, respectively. The values 0.0 to 0.8% obtained at FR1 are comparable with the separation loss of 3.68% - 16% (Osueke, 2013) and 1.85 to 8.46% for sorghum (Olaoye, 2011).

Cleaning efficiency of the machine for soybean samples

The CE of soybean as feed rate and COF are varied is presented in Figure 5, which shows that as feed rates increase, CE is reduced for all the surfaces considered. The CPT and PLYWD surface maintained high CE values at FR1 and FR2, these effects may be attributed to the ease of grain rebound on the surface and the relative retardation of the chaff as they moved on the surfaces. The CE values from the RG surface are lower than CARPT and PLYWD, the surface may have impeded both grains and chaff alike, although its CE is higher than MS, which had better grain rebound but did not impede the movement of chaff. Also, the reduction in CE as the feed rate is increased can be seen in the Figure 5.

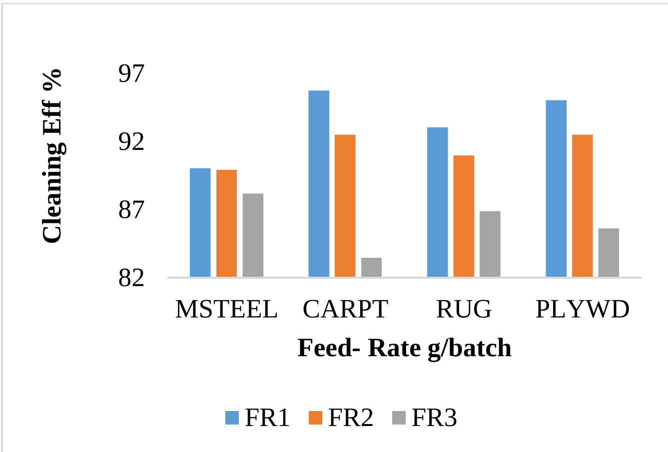

Figure 5: Variation of cleaning efficiency of soybean with feed rates for various surfaces.

The maximum cleaning efficiencies for the various crops were 89.9, 95.8, 93.1 and 95.0% for MSTEEL, CARPT, RUG and PLYWD surfaces, respectively. The 95.8% (CPT) and 95.0%

(PLYWD`) CE values are comparable to 78.0 - 88.0% CE (Qabaradin and Tsegaye, 2021) for an axial flow soybean thresher. The rate at which CE is reduced is 1.682, 0.598, 0.162 and 0.09 kg/s for CARPT, RUG, MSTEEL and PLYWD, respectively. As the feed rate is increased, the COF separation becomes inefficient. The importance of COF is underlined by the 6.0, 3.5 and 0.8 kg/s rates for sorghum, soybean and millet reported for conventional equipment (Muhammad *et al*. 2013).

Cleaning efficiency of the machine for cowpea samples

The variation of cleaning efficiency with feed rate and surfaces for cowpeas is presented in Figure 6. Comparing the CE values (96-83%) of the Soybean experiment from Figure 5, the values for Cowpea (97-94%) are higher. Also, the samples from the cowpea experiment responded to an increase in feed rate in a gradual manner compared to soybean because the impurity in cowpea is lighter and lesser in quantity compared to the heavier stalks, sticks and chaff that soybean is threshed with.

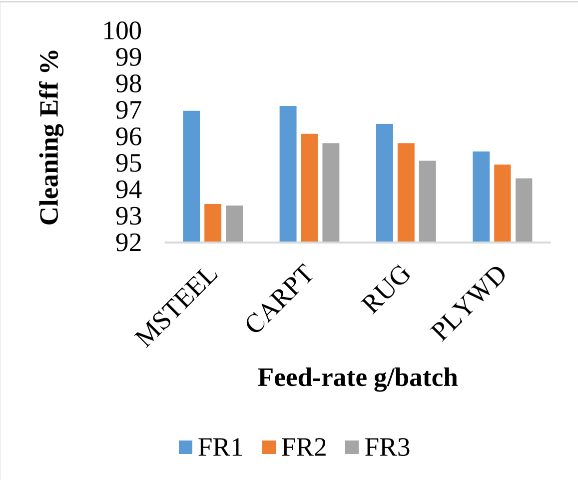

Figure 6: Variation of cleaning efficiency of cowpeas with feed rates for various surfaces.

Also, except for MSTEEL, the rebound and frictional retardation effect of samples from the three other surfaces were similar. RUG surface gave a better CE at an increased feed rate compared to the experiment using soybean, because it could trap the type of chaff on soybean rather than the cowpea chaff. The CE for the cowpea samples was 96.9, 97.2, 96.5 and 95.4% for MSTEEL, CARPT, RUG and PLYWD surfaces, respectively. While the lowest CE values were 94.4 - 95.4% (PLYWD). The obtained CE values are comparable with 97-98% CE of wheat (Ahmad et al. 2013), and 95.60% CE for cowpea (Irtwange, 2009).

Machine grain output

The soybean and cowpea grain output from the different surfaces are shown in Figure 7, the yields for cowpea are higher than for soybean, because there were more grains in cowpea compared to soybean, which had more extraneous materials (stalk, sticks, chaff). The PLYWD and CARPT surfaces had the most output, though there was no statistical difference (5% significance) for the other treatments.

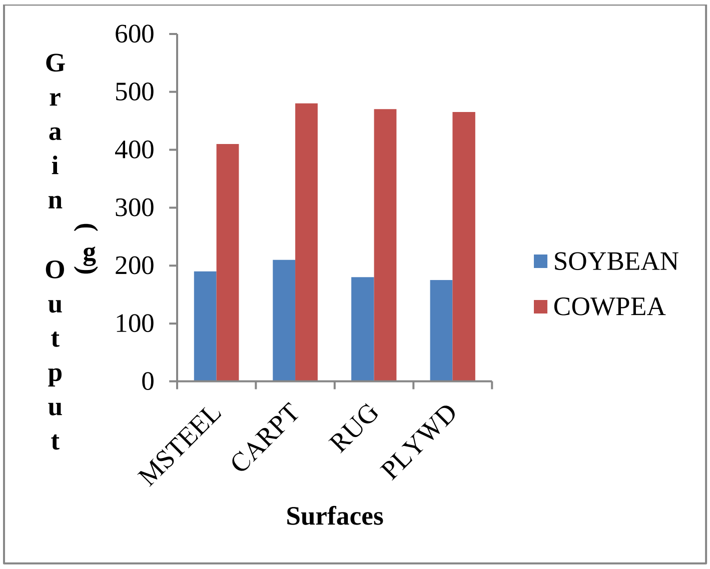

Figure 7: Grain output (g) of soybean and cowpea for various surfaces

Statistical analysis and ANOVA results of the experiment

The analysis of variance (ANOVA) of the main effects of soybean is shown in Table 1. The threshing efficiency was significantly affected by the type of surface S (28.82 %) and feed rate FR (4.00 g), while the amount of impurity did not affect the TE. Also, impurity (92.53%) and batch weight (22.21 g) were the most significant at 1 and 5% on CE, while the type of surface was not significant. Among first-order effects, only the interactions between the type of surface and feed rate were significant on the amount of broken seed, threshing efficiency and seed output. Other effects are further highlighted in the table.

Table 1: ANOVA results of the threshing unit performances

Source of Variation	d.f.	F-Value				
		CE	BRKNWT	BRKPER	THRSPER	SEDWT
Replication	2					
Impurity (I)	1	92.53**	3.91*	0.08 ns	0.09 ns	22.12**
Surface (S)	3	2.50 ns	43.58**	28.87**	28.82**	3.34*
Batch weight (BW)	2	22.21**	3.79*	4.05*	4.00*	99.30**
I x S	3	1.41 ns	1.49 ns	2.26 ns	2.29 ns	1.07 ns
I x BW	2	2.50 ns	3.96*	2.91 ns	2.94 ns	4.43**
S x BW	6	0.92 ns	4.89**	4.09*	4.10*	2.20*
I x S x BW	6	1.69 ns	8.60**	7.98**	7.94**	0.64 ns

**Highly significant at 1% level;*significant at 5% level; ns, non-significant; df, degrees of freedom. CE = Cleaning efficiency, BRKNWT= Broken seed weight, BRKPER = Broken seed percentage THRSPER = Threshed seed percentage SEDW T = Seed weight

CONCLUSIONS

The possibility and advantage of exploiting the COF of crops as a processing parameter in motorized legume threshing machines were verified using cowpea and soybean grains. It was found that depending on the harvesting practices adopted during crop harvest, the cleaning efficiency and threshing efficiency of grains can be further increased, while the amount of losses is reduced. This will encourage farmers to adopt indigenous technologies, which would aid their productivity and ensure food sustainability for the populace. The research was not exhaustive; other factors such as blower speed, moisture content and different crop varieties can be considered in further performance evaluations.

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