Development of a Treadle Operated Abrasive-Cylinder for Threshing Cowpea

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ABSTRACT
A treadle operated cowpea thresher was designed and developed for threshing cowpea. The threshing surface was created between the perforated threshing drum and a wood surface mounted on the hopper walls. The adjustment of drum-wood (concave) clearance was done by sliding the wood on the inside of the hopper closer or away from the threshing drum. The machine was tested for different speeds of the threshing drum (50, 75, 100 and 125 rpm) and three different levels of moisture content (11 %, 13 % and 15 % wb) for the two varieties of cowpea used for the testing of the machine. Tests were carried out on two varieties of cowpea IT86D-719 and IT84S-2246-4. Results show that the machine has a minimum capacity of 15 kg/hr. The IT86D-719 variety could be threshed at threshing efficiency of 95%, with percentage of split of 5% and unthreshed pod of 0.6% at the cylinder speed of 100 rpm and at moisture content 12% wb. The IT84S-2246-4 variety, threshing is feasible at threshing efficiency of 97%, percentage split of 5% and percentage of unthreshed pod of 2% at cylinder speed of 100 rpm and moisture content of 11% wb.

Keywords: Cowpea, Treadle, Threshing Efficiency, Grating Surface, Abrasive Cylinder

INTRODUCTION
Cowpea is grown in Nigeria as a cereal crop and it is one of the staple crops that provide much needed protein requirement in the dietary table. A lot of Nigerian earn their living directly or indirectly through the cultivation of cowpea. Cowpea is consumed in several ways when prepared. It could be prepared in several ways for consumption (boiling, grinding, and processing into “Akara ball”, “moinmoin”, etc), (Lawrence, 2006). The chaff can be fed to livestock, while the seeds are dried to 8-10% moisture content and sold or fumigated and stored for sale at a later date.

Production of cowpea 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. 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.

Allen and Watt (1998) and Bruce et al. (2001) identified that, improper harvesting and threshing usually results in losses of up to 5% of the crop; therefore, better production techniques alone are not sufficient 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 minimize feed losses. Kepner et al. (1978) discussed some factors affecting the efficiency of threshing operation. They are identified as feeding method, cylinder speed, concave-to-cylinder clearance and moisture content.

Ghaly (1985) reported that damage occurs primarily because of the impact of the blows received by the seeds during the threshing process. The damage may be visible (external) or invisible (internal). The latter type was determined by germination test. Seed damage does not represent a direct loss of yield except for seeds broken into pieces that are too small to be recovered. According to Klein and Haugh (1975) seed damage may however reduce the quality and volume of products depending upon the intended use of grains. Internal seed damage, as it affects germination is an important consideration when grains are to be used for planting purpose.

It is important to note that manual system of threshing of cowpea provides the basis for exploitation of women and children labour. Hence, the need for appropriate technology that will combine both the threshing and cleaning (separation of the grain from the chaff) operations together at considerable efficiency and low initial operating cost.

Most of the existing cowpea thresher for threshing of cowpea employ a tooth peg as threshing device with accompany power driven mechanism. High and excessive energy are wasted through the currently available mechanical thresher (Umogbai and Shehu, 2009; Maunde et al., 2010). The choice of the selected abrasive cylinder as threshing mechanism is to ensure optimum application of power during threshing operation because cowpea pods are soft and easy to break.
The main objective of this study is to design and construct a treadle operated cowpea thresher and to utilize a perforated metal sheet wrapped around a cylindrical drum as a threshing mechanism. The threshing device is to be operated by a treadle assembly.

**DESIGN CONSIDERATIONS AND CALCULATIONS**

The treadle cowpea thresher machine in view is to thresh cowpea at an appreciable efficiency, with lower cost, initial investment and lower power requirement. The total volumetric capacity the cowpea hopper is estimated at 0.0201 m³. Figure 1 shows the isometric view of the thresher. It consists of a feeding hopper, threshing unit, main frame, main shaft carrying the threshing drum, threshed material outlet collector unit, the pedaling unit (power transmission unit) consists of treadle pedal, pulleys, transmission belt and a fly wheel assembly for the storage of energy needed for continuous rotation the cylindrical drum.

**The threshing unit**

Loaded cowpea pod in the hopper flows directly into the threshing unit. The perforated threshing drum is wrapped on a cylindrical shaft to create an abrasive surface for the threshing process of cowpea as shown in the plan view of the machine (Figure 2). The threshing drum is supported on a steel shaft and the shaft is held firmly on the supporting body frame of two rigid ball bearings.

![Figure 1. The Isometric View of a Treadle Operated Cowpea Thresher](image-url)
The length of the cylinder (L) = 300 mm and diameter of 200 mm were used. The main frame houses the main shaft that holds the threshing cylinder and it also provides support for side covers of the machine as presented in Figure 1.

**Design of Main Shaft**

The main shaft is the transmission element of the threshing operation. It carries the threshing drum, the flywheel at one end, and the smaller pulley at the other end. It was properly selected based on calculations and the properties of materials so as to withstand stress and strain from the imposed loads. The shaft is made of steel material because of the load that would be impacted on the shaft. Steel is desired where strength, reliable resistance to shock and repeated loading are required. Maximum allowable stress, \((s_s)\) and shear stress for \((\vartheta_s)\) for steel shaft are 1.2 \(\times 10^8\) Pa and 8 \(\times 10^7\) Pa, respectively (Olaoye, 1990). For solid shaft, the diameter is obtained by equation 1.

\[
d^3 = \frac{16}{\pi S} \sqrt{(K_b M_b)^2 + (K_t M_t)^2}
\]

Equation 1

where:
- \(M_b\) = the maximum bending moment of 280 N m from the bedding moment diagram analysis
- \(M_t\) = maximum torque exerted by the various load on the shaft = 36.3 N m
- \(S = S_s\) for maximum stress or \(\vartheta_s\) for maximum shear stress
- Values of \(k_t = 1.5\) and \(k_b = 2\) these are chosen to reflect gradual method of loading cowpea during operation.

Based on maximum shear stress \((\vartheta_s)\) of 8 \(\times 10^7\) Pa and maximum allowable stress, \((s_s)\) of 1.2 \(\times 10^8\) Pa the calculated diameters are 0.026 m and 0.03 m, respectively. From the analysis above, the shaft diameter should not be less than 30 mm. Hence, a 35 mm diameter shaft was used for the construction.

**Power Transmission Unit (Treadle Arrangement)**

The treadle assembly consist of the pedal and a flat bar connected together through 300 mm pulley to produce a rotary motion on the pulley as a result of reciprocating motion of the pedal. The pedaling unit is made of mild steel angle iron. The aim is to design a link of correct length and to ensure rigidity for satisfactory performance. It operates on the principle of 4 – bar linkage mechanism. Figure 3 shows the illustration of the 4 – bar linkage. P is the driving pulley to which the bar linkage is linked. The four bars are BC, AB, AD and DC. Point B is the crank point, and D is the pivot for the treadle. Equation 2 governs the principles of operation of a 4 – bar linkage system.
Where: $L_1$ = The length of link 1 (shortest link) = 38 mm
$L_2$ = The length of linkage bar to be determined
$L_3$ = Centre distance between the pivot and point of contact of the linkage bar on the treadle = 108 mm
$L_4$ = The distance between the centre of the pulley and the pivot point 340 mm.

$L_3 + L_4 = L_3 + L_2$ and this implies that $(370 - 108)$ mm = 270 mm. Therefore, the actual length of the link should be less than 270 mm.

The belt and pulleys are the transmission elements through which the threshing shaft is linked to the power treadle assembly. Two pulleys of diameters 300 mm and 50 mm were employed. The 300 mm pulley is attached to the treadle pedaling unit while the 50 mm pulley is attached to the main driving shaft. This is aimed at increasing the turning speed (Osborne, 1977; Olaoye, 2004). Both pulleys are made of cast iron and are fixed to the shaft with triangular keys. The belt length and tension were determined by using equations 3 and 4 respectively. Standard pulley belts length of 1146.3 mm and torque of 115.5 N were selected.

$$L = 2C + \frac{\pi}{2}(P_{d1} + P_{d2}) + \frac{(P_{d1} + P_{d2})^2}{4C}$$  \hspace{1cm} \text{Eqn. 3}

Where, $L$= length of the belt (mm), $P_d$ = pitch Diameter (mm), $C$ = centre distance = $c_1 = \frac{1}{2}(0.2 + 0.1) + 0.2 = 300$ mm.

$$T_R = \frac{(T_1 - T_2) DR}{2}$$ \hspace{1cm} \text{Eqn. 4 (Gary et al., 1984)}

where, $T_1$ and $T_2 = 1503.5$ and $349.7$, respectively
$D_R$ = driving pulley diameter (m) = 0.2m
$T_g$ = Torque developed

The fly wheel
It is an important component of the machine. It is fixed on one end of the main shaft. It ensures the balance in motion as a result of the imposed load and causes the return of the reciprocating motion of the pedal.
Fabrication Processes

The construction processes were carried out in the fabrication workshop, Department and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria. The basic manufacturing processes which include cutting, primary shaping and joining processes were undertaken. The front view of the machine is presented as Figure 4.

![Figure 4: Side View of the Cow Pea Thresher](image)

Operation of the machine

The threshing of the pod into grain is carried out with the machine in the following ways; The flywheel will be rotated with hand so as to allow the machine to gather momentum, this will cause the pedal to come up, it will be pressed by the foot and the threshing drum will start rotating. The rotational motion of the threshing drum is as a result of the reciprocating motion of the bar that connects the larger pulley with the pedal. The pod can then be fed into the hopper for threshing.

Machine Testing

Two varieties of cowpea IT86D – 719 at moisture content 10%, 12% and 15%, with concave clearance of 9 mm and IT84s-2246-4 at moisture content 11%, 13% and 15%, with concave clearance of 8 mm were used for the test. Each variety was tested with 4 different speeds of threshing drum at 50, 75, 100 and 125 rpm. The concave clearance was determined based on the major diameter of each variety that was threshed.

Table 1 contains the results of the threshing efficiency, the percentage split of the cowpea at different moisture content and speed. Table 2 contains the results of the threshing efficiency, the percentage split of the cowpea at different moisture content and speed.

Discussion of results

Results shown in Figures 5 to 8 and Tables 1 and 2 revealed that for variety IT86D-719, at the moisture content 12% and the speed of 100 rpm could possibly represent acceptable threshing conditions of the variety. Threshing efficiency of 95% was feasible has percentage of split of 5% been observed. It was observed that at higher cylinder speed of 125 rpm it is possible to obtain threshing efficiency of 96% but at this state higher value of percentage split was also recorded with increased unthreshed pod. At higher moisture content the threshing efficiency decreases to 92% even at the highest cylinder speed examined. For the second variety IT84s-2246-4, the threshing efficiency of 97% at moisture content 11% and cylinder speed of 100 rpm were...
observed as appropriate threshing conditions for this variety of cowpea. It was observed that at higher cylinder speed of 125 rpm it is possible to obtain threshing efficiency of 98% but at this state higher value of percentage split was also recorded with increased unthreshed pod. The percentage of unthreshed pod also doubled from 5% at cylinder speed of 100 rpm to 11% at 125 rpm. At higher moisture content the threshing efficiency decreases to 92% at the same cylinder speed (100 rpm). Fig 5 to 8 show the trends of variation between the threshing efficiency versus speed and percentage split (damage) versus threshing speed for each of the variety studied.
Table 1: The threshing efficiency and percentage split of the IT86D-719 cowpea at different moisture content and speed

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture content % Wb</th>
<th>Speed r.p.m</th>
<th>Threshing efficiency %</th>
<th>Split %</th>
<th>Unthreshed %</th>
<th>% weight of chaff in the collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 IT86D-719</td>
<td>15</td>
<td>50</td>
<td>82</td>
<td>1</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>50</td>
<td>84</td>
<td>3</td>
<td>8</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>50</td>
<td>86</td>
<td>4</td>
<td>6</td>
<td>75</td>
</tr>
<tr>
<td>V2 IT86D-719</td>
<td>15</td>
<td>75</td>
<td>87</td>
<td>4</td>
<td>6</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>75</td>
<td>89</td>
<td>5</td>
<td>5</td>
<td>60</td>
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<tr>
<td></td>
<td>10</td>
<td>75</td>
<td>90</td>
<td>7</td>
<td>4</td>
<td>58</td>
</tr>
<tr>
<td>V3 IT86D-719</td>
<td>15</td>
<td>100</td>
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<td>5</td>
<td>2</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>100</td>
<td>91</td>
<td>5</td>
<td>1.5</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>100</td>
<td>92</td>
<td>6</td>
<td>0.9</td>
<td>50</td>
</tr>
<tr>
<td>V4 IT86D-719</td>
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<td>125</td>
<td>92</td>
<td>6</td>
<td>0.8</td>
<td>49</td>
</tr>
<tr>
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<td>96</td>
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<td>0.6</td>
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<td></td>
<td>10</td>
<td>125</td>
<td>98</td>
<td>10</td>
<td>0.4</td>
<td>40</td>
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</tbody>
</table>

Table 2: The threshing efficiency and percentage split of the IT84S-2246-4 cowpea at different moisture content and speed

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture content % Wb</th>
<th>Speed r.p.m</th>
<th>Threshing efficiency %</th>
<th>Split %</th>
<th>Unthreshed %</th>
<th>% weight of chaff in the collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 IT84S-2246-4</td>
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<td>86</td>
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<td></td>
<td>11</td>
<td>50</td>
<td>82</td>
<td>4</td>
<td>9</td>
<td>82</td>
</tr>
<tr>
<td>V2 IT84S-2246-4</td>
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<td>75</td>
<td>84</td>
<td>5</td>
<td>8</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>13</td>
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<td>86</td>
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<td>68</td>
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<tr>
<td></td>
<td>11</td>
<td>75</td>
<td>88</td>
<td>7</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>V3 IT84S-2246-4</td>
<td>15</td>
<td>100</td>
<td>90</td>
<td>7</td>
<td>5</td>
<td>61</td>
</tr>
<tr>
<td></td>
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<td>100</td>
<td>95</td>
<td>9</td>
<td>4</td>
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</tr>
<tr>
<td>V4 IT84S-2246-4</td>
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<td>96</td>
<td>9</td>
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<td>125</td>
<td>98</td>
<td>11</td>
<td>0.5</td>
<td>45</td>
</tr>
</tbody>
</table>

Fig 5: Variation of Machine efficiency with Speed at different moisture content for Variety IT86D – 719
Fig 6: Variation of Machine efficiency with Speed at different moisture content for Variety IT84S – 2246– 4
CONCLUSIONS

A treadle cow pea thresher was designed and constructed with machine capacity of 15 kg/hr. The treadle assembly was provided to supply the required energy needed to operate the abrasive grating drum that create that surface for the threshing action.

The preliminary machine testing was undertaken. The effects of moisture content, varieties of cowpea and cylinder speed were investigated on the threshing efficiency, percentage split, unthreshed grain.

At the moisture content of 12% and the cylinder speed of 100 rpm it was established that the machine operates at threshing efficiency of 95% with percentage grain split of 5% for the variety IT86D-719.

Also, for the second variety IT84S-2246 – 4, the threshing efficiency of 97% at moisture content 11% and cylinder speed of 100 rpm were observed as appropriate threshing conditions for this variety of cowpea with percentage split of 5%.
REFERENCES