Design and evaluation of a cleaning machine

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ABSTRACT

A device for cleaning threshed seeds was been developed. The cleaning system consists of an air – blast fan and a reciprocating shaker containing replaceable sieve for different crop seeds and a collecting pan. The performance of the prototype was evaluated in terms of percentage cleaning efficiency and grain loss at various levels of feed rates, and fan speeds. The test crops used were sorghum, soybean and millet. The best performance was obtained at cleaning efficiencies of 95, 98 and 91% and percentage grain losses of 0.63, 0.81 and 0.75% respectively for sorghum soybean and millet. The optimum values of feed rates were 4, 2.5 and 3.5 kg/s while these of fan speeds were 415, 505 and 582 rpm for the respective crops.

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Introduction

Cleaning of grain or winnowing is one of the important postharvest processes done in preparing sorghum as food or any industrial raw material. It involves the removal of chaff and other debris from the grain. There are quite a number of factors that affect the performance in terms of cleanliness and grain loss during the operation. Such factors include amount of wind or air velocity, feed rate, shaker frequency, dimension of sieve opening, sieve tilt angle, crop variety and moisture content (Kirk et al., 1978 and Braide, 1979; Kashayap and Pandya, 1966; Nurul Islam, 1980 and Sharma, 1976).

A good cleaning machine should remove all chaff straws and plant debris with very little grain loss. In Nigeria, particularly in the North, crop cleaning is part of women’s contribution in processing of grains. A woven circular tray made from the back of sorghum stalk of average diameter of 500 mm is used. The cleaning operation is usually done in an open space when there is free flow of natural wind. A batch of about one kilogram of threshed seeds is placed on the tray and then shaken to and fro, upwards and downwards in a systematic manner. Due to the tossing and reciprocating motion of the tray and with the aid of natural air current, the lighter material moves towards the front edge of the tray until it falls out and gets blown off from the winnower. Subsequently, only the clean seeds would remain on the tray. The time taken to clean a batch of 1 kilogram of uncleaned seeds ranges between seven to twelve minutes depending on the winnower’s skill, the required cleanliness, grain/non-grain ratio, amount and stability of the natural air current and other environmental factors.

The long hours associated with the traditional method results in fatigue, loss of concentration and consequently, reduction in separation quality. So often the natural wind condition may not be favourable for the operation and the result is increased time of operation and drudgery.

Institute for Agricultural Research (1970) developed various crop threshers which were usually combined with cleaning systems. The output of the machines were low due to the presence of the threshing units whose threshing capacities were not significantly higher than manual threshing using sticks. The threshing unit also convey long straws onto the shaker which results in increase grain loss. The high cost of thresher – cleaner machine is due to the additional cost of the threshing component which is not needed by an average farmer. The average farmer finds it more economical to thresh these crops manually but requires extremely high labour and time to clean the grain using the manual method. A machine for cleaning grains is, therefore needed to satisfy both small and average farmer requirements.

Materials And Methods

The Physical and Engineering properties of the grain and non-grain material was considered in the determination of the design parameters of the cleaning device. These properties include size, shape and angle of repose of the grain. Also considered were moisture content, density, and terminal velocity of the grain and non-grain material. The parameters established include:

(i) Fan size and speed
(ii) Sieve mesh
(iii) Shaker frequency and amplitude
(iv) Shaker tilt angle
(v) Power requirement

Fig. 1. The major components of the prototype of the winnowing machine

**Description of the prototype**

The machine consists mainly of the hopper, the fan, the shaker and the supporting frame. The hopper is of trapezoidal shape and made of gauge 18 metal sheet. The sides slant inwards to form a small outlet situated above the shaker. The fan has blades enclosed in the casing whose outlet is located to deliver current of air over the shaker along the
reciprocation direction of the shaker. The shaker assembly consists of a sieve, grain collecting pan and the clean grain outlet. It is suspended from the frame on four bearings each attached to 12 mm x 100 mm bolt and nut to facilitate adjustment of the tilt angle ranging from 1 to 30°. A crank mechanism with adjustable crank length and connecting rod to achieve various levels of reciprocating amplitudes was employed to drive the shaker. A 2.24 kW prime-mover was mounted on the frame to power the fan and the crank mechanism using belt and pulley drive. The frame which holds all the components together at their relative positions was constructed using 3 mm x 8 mm x 38 mm angle iron. The major components of the prototype are shown in the assembly drawing (Fig.1) and Table 1 reveals the description and specification of the winnowing machine.

<table>
<thead>
<tr>
<th>No. of Item</th>
<th>Description and specification</th>
<th>Qty</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prime mover (Electro motor)(2 hp 2000rpm)</td>
<td>1</td>
<td>M.S.</td>
</tr>
<tr>
<td>2</td>
<td>Pulley (Ø100 x 25mm)</td>
<td>1</td>
<td>M.S.</td>
</tr>
<tr>
<td>3</td>
<td>Pulley (Ø180 x 25mm)</td>
<td>1</td>
<td>M.S.</td>
</tr>
<tr>
<td>4</td>
<td>Pulley (Ø160 x 25mm)</td>
<td>1</td>
<td>M.S.</td>
</tr>
<tr>
<td>5</td>
<td>Belt (v- type, 1200 x10x9mm)</td>
<td>1</td>
<td>Leather</td>
</tr>
<tr>
<td>6</td>
<td>Belt (v- type, 1100 x10x9mm)</td>
<td>1</td>
<td>Leather</td>
</tr>
<tr>
<td>7</td>
<td>Flopper ( 400 x 300 x 300mm)</td>
<td>1</td>
<td>M.S. sheet (Gauge 18)</td>
</tr>
<tr>
<td>8</td>
<td>Shaker (680 x 400 x 530mm)</td>
<td>1</td>
<td>M.S. sheet (Gauge 16)</td>
</tr>
<tr>
<td>9</td>
<td>Bolt (Ø14mm)</td>
<td>1</td>
<td>M.S.</td>
</tr>
<tr>
<td>10</td>
<td>Fan Housing (Ø500mm x 430mm)</td>
<td>1</td>
<td>M.S. sheet (Gauge 18)</td>
</tr>
<tr>
<td>11</td>
<td>Frame (25 x 25 mm angle iron)</td>
<td>1</td>
<td>M.S. Angle iron</td>
</tr>
<tr>
<td>12</td>
<td>Connecting rod (Ø25mm iron rod)</td>
<td>1</td>
<td>M.S. Rod</td>
</tr>
<tr>
<td>13</td>
<td>Fan shaft (Ø25 x 460mm)</td>
<td>1</td>
<td>M.S. Rod</td>
</tr>
<tr>
<td>14</td>
<td>Grain outlet (280 x 130 x100mm)</td>
<td>1</td>
<td>M.S. sheet (Gauge 18)</td>
</tr>
</tbody>
</table>

Scale
1:5
Dimension in mm

Operation of the prototype
The machine is operated by starting the prime mover which drives the fan and the shaker assembly simultaneously. A batch, at a time, of threshed grain containing both grain and non-grain material is then fed into the machine through the hopper. It flows down by gravity and passes through the hopper outlet and drop across the fan air current onto the shaker sieve. The non-grain material being of lower density than the grain, is blown out of the machine through the outer end of the shaker. The grain material passes through the sieve mesh onto the grain collecting pan and subsequently, flows down the slope of the pan and the grain outlet where it is collected. The broken stalks and other material that reach the surface of the sieve are pushed by the air current and discharged at the outer end of the shaker.

Test procedure
The test involves taking a pair of samples which were at the grain outlet and the non-grain (unwanted material) outlet. The weights of grain and other material in each sample were recorded. The procedure was repeated for each throughput. The amount of debris in clean grain outlet samples determined the cleanliness (cleaning efficiency) while the amount of grain found in non-grain outlet samples determines the grain loss. The expressions used for calculating the percent cleaning efficiency and percent grain loss were as follows:

\[(i)\quad E_C = \frac{W_G}{W_{TG}} \times 100\]

\[(ii)\quad G_L = \left[\frac{W_{GN}}{W_G + W_{GN}}\right] \times 100\]

Where,
\(E_C\) = Percent cleaning efficiency (%)
\(G_L\) = Percent grain loss (%)
\(W_G\) = Weight of grain material in clean-grain sample (kg)
\(W_{TG}\) = Weight of total material in clean-grain sample (kg)
\(W_{GN}\) = Weight of grain material in non-grain sample (kg)
\(W_{TN}\) = Weight of total material in non-grain sample (kg)

The data was recorded at five levels each, of feed rate, and fan speed while each experimental unit was replicated three times.
Results And Discussion

Effect of feed rate on the machine performance

The effect of feed rate on cleaning efficiency and grain loss is shown in Fig. 2 for sorghum, soybean and millet. The regression analysis showed high negative linear correlation of feed rate with cleaning efficiency for each of the three crops with coefficient of determination of 0.95, 0.93 and 0.96 respectively. They attained 100 % cleanliness at feed rates of 13.5, 11.5 and 5.8 kg/s respectively. The cleaning efficiency decreased with increase in feed rate at the rate of 6.0, 3.5 and 0.8 % per kg/s respectively for sorghum, soybean and millet. This showed that millet has highest response to change in feed rate, followed by sorghum and then soybean. This is due to the fact that as the feed rate increased, the material flowing across the air current forms thicker blanket and, therefore, increasingly more difficult for air current to penetrate and flush out the unwanted material and subsequently decreased the cleanliness as more of the debris passed through the sieve holes together with the grain.

The figure also presents the regression courses of percentage grain loss against feed rate for the three crops. They have polynomial relationship with minimum percentage grain losses of 4.0, 2.5 and 6.0 % corresponding to feed rates of 0.81, 0.63 and 0.75 kg/s respectively for sorghum, soybean and millet. The percentage grain loss for each of the crops increased either with another increase or decrease in feed rate from the minimum points. This phenomenon could be explained due to the fact that as the feed rate gradually increased the mass flow across the air current could still allow air to penetrate and flush out unwanted material. This happened up to a point corresponding to minimum grain loss after which the feed rate reached a level that the blanket effect could completely prevent air current penetration through the material mass flow and consequently the whole material reached the sieve top and therefore, more grain were dragged along the sieve surface and expelled through unwanted material outlet which gave rise to increase in grain loss after the minimum point.

The optimum cleaning efficiencies for the various crops were considered as those corresponding to their respective minimum percentage grain losses which were 95, 98 and 91 % for sorghum, soybean and millet.

Effect of fan speed on the machine performance

Fan speed exhibited positive linear relationship with cleaning efficiency with coefficient of determination of 0.93, 0.94 and 0.97 respectively for sorghum, soybean and millet as shown in Fig. 3. The rates of percentage increase in cleanliness with increase in fan speeds were 0.06, 0.05 and 0.08 % per rpm and attained 100% cleanliness at fan speeds corresponding to 650, 765 and 550 respectively.

Relationship between fan speed and percentage grain loss was polynomial as shown in Fig. 3. There were minimum values of grain loss for the respective crops at 1.05, 1.3 and 4.8 % corresponding to fan speeds of 350, 400 and...
The grain loss for each of the crops increased with either further decrease or increase of fan speed from the value corresponding to minimum grain loss.

The percentage cleaning efficiency for the three crops corresponding to the minimum percentage grain loss were 82, 85 and 72 % for sorghum, soybean and millet respectively. These values indicated unsatisfactory cleanliness and cannot represent the optimum values. Concession had been made to consider fan speeds that gave better cleanliness at the expense of increase in grain loss for each of the crops. Thus, average value of fan speed corresponding to minimum grain loss and that at 100% cleanliness for each of the crops had been considered as the optimum fan speed, together with its corresponding grain loss and cleanliness. These optimum values of percentage grain losses were 4.0, 3.5 and 5.5 % and the corresponding percentage cleaning efficiencies were 92, 93 and 86 % respectively for Up to a point.

Conclusion
A cleaning machine for crop seeds has been developed and tested and the following conclusion were made:

(i) The cleaning efficiency of the machine indicated negative correlation with feed rate for the crops tested. There was optimum cleanliness at feed rates less than 0.25kg/s for the three crops tested. However, it increased with increase in fan speed and attained 100 % at 650, 770 and 590 rpm for sorghum, soybean and millet respectively.

(ii) The percentage grain loss exhibited curvilinear relationship with both feed rate and fan speed. There were minimum percentage grain loss corresponding to feed rates of 0.31, 0.40 and 0.37 kg/s and fan speeds of 350, 400 and 250 rpm respectively for sorghum, soybean and millet.

(iii) The combination of feed rate and fan speed for optimum cleanliness and grain loss for sorghum, soybean and millet were 0.23, 0.30 and 0.27 kg/s feed rates and 505, 582 and 415 rpm fan speeds respectively.

(iv) The maximum output of the cleaner for sorghum, soybean and millet were 414, 540 and 486 kg/s respectively.

References