Development and Performance Evaluation of a Spring-Loaded Hand Operated Maize Sheller with Variable Mechanisms

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Abstract. A spring-press, variable mechanism hand operated maize sheller was developed, constructed and tested with corn cobs at 12.6% moisture content, wet basis (w.b) and its shelling performances compared. The machine is lever operated with a spring load-return mechanism and a cob constrictor with changeable shelling mechanisms (spike tooth, rasp bar and star tooth), and a tilted tray for grain collection. The overall dimension of the machine is 520mm x 520mm x 400mm. The machine overall performance is 20.62kg/hr shelling capacity, 85.13% shelling efficiency and 2.13% kernel damage. Comparing the performance of the three shelling mechanisms; rasp bar, spike tooth and star tooth, shelling capacity (16.2, 26.0, 19.67) kg/hr.; shelling efficiency (82.22%, 87.19%, 85.97%); and % kernel damage (0.00, 0.74, 0.51) respectively, the star mechanism has a higher capacity of 26.0kg/hr. The mean kernel damage is higher for star tooth, whereas it is zero for rasp bar. In comparison with conventional hand-palm shelling method (100% shelling efficiency, 13.83 kg/hr shelling capacity and 0% kernel damage), the hand operated sheller has a better output capacity, reasonable shelling efficiency but slightly higher kernel damage. By implication, machine performance efficiency does not give a true reflection of how effective a system work until the machine capacity is determined. The sheller ease household shelling maize for consumption with initial low production cost of N13, 100.00 (~$30).

1.0 Introduction

Maize (corn) is the most important staple cereal crops after wheat and rice in the world, providing nutrient for human and animals and serving as a basic raw material for the production of starch, oil and protein, alcoholic beverages, food sweeteners and more recently, fuel. It is because of the importance placed on maize that makes its handling, processing and preservation within optimum condition to be analysed. Maize shelling is one of the difficult processing technologies which has become a more widely accepted innovative process involving a multitude of diverse stakeholders [1, 2]. Maize was traditionally threshed with bare hand directly removing the kernels pressing it between thumb and hand palm or by rubbing the maize cobs against one another by hand. Other popular methods include the use of pastel and mortal, bicycle wheels etc. These methods are still used in the rural areas today. The low output, time consuming, boredom and extra strength requirements by these methods are unsatisfactory and do not support large scale shelling of maize especially for commercial purposes.

Technological advancements in maize processing had at sundry times had led to different levels of development which include the conventional bare hand shelling, hand shelling with aids/tool, hand-crank shellers and motorised industrial maize shelling machine to ease corn processing with high degree of production volume and efficiency [3-5]. In many developing countries, the highly efficient motorised shelling equipment are often unaffordable or difficult to obtain by subsistence farmers. The industrial maize shellers have high cost range of US $ 1,200 – 1800, and the small hand cranked or petal powered maize shellers which costs US $ 20-50 [6], are more than what many families can afford. The highly productive hand shellers with low energy shelling requirement and the transportation difficulties of mechanized equipment and stationary hand operated devices within farms pose difficulties to farmers which may require to travel long distances to process their crops.
Since the introduction of the modern maize sheller in the 1800's by Lester E. Denison hand-operated machine, the basic design and function of this machine has remained the same with most modern-day maize shellers bearing a strong resemblance to the original models designed by inventors like Denison and Briggs. In the early 1900's, a number of engine-powered maize shellers were developed which provided the foundation for modern commercial and agricultural shellers. These large stream-powered machines have now been mostly replaced with the use of the modern combine harvester that strips the kernels from the maize cob while the maize is being harvested in the field. In 2015, [7] assessed the level of adoption of mechanical maize shelling technologies are quite high, (76.7%) as compared to 23.3% who still engaged in hand shelling of maize. This suggested that a convergence of participatory innovation development framework is likely to be more beneficial to the farmers than the present technology – transfer approach to innovation development [8].

Today’s intermediate technologies in corn shelling under progressive development necessitated active research in machine ergonomics, size and shelling mechanism designs. This article report a positive contribution the development of a satisfactory, affordable and effective hand-crank sheller capable of utilizing different shelling mechanisms.

2.0 Materials and Method

2.1 Material selection

The materials for construction of the machine were selected based on availability, mechanical properties and economic considerations. The materials were sourced locally from the open market and metal junk houses. Two major materials used in fabrication are mild steel rods and plate.

2.1.1 Machine development considerations

The following were put into consideration while developing the machine:

1. Availability of materials of construction: The development of this modified hand operated maize sheller is aids by its possible construction from locally sourced materials from junk stores.

2. Crop factors which include physical and mechanical properties: Considerations in the determination of crop geometry e.g. shapes and sizes etc. was made using clustering criteria [9, 10] and the combined features of length of maize cob, weight and axial diameters. Other crop factors include moisture content of the crop.

3. Shelling mechanism: Three shelling mechanisms were developed based on the principles of crop shelling. These mechanisms include spike tooth, rasp bar and star tooth. The resting plate (in-feed chute) supports the material while the moving blade slices the material against the stationary plate.

4. Loading: a spring load-return mechanism ease the operation of the lever

5. Cost: Low cost of materials of construction for affordability by local farmers

2.1.2 Theoretical framework of sheller development

The machine principle is to shell and separate the maize cob from the grains. The machine works on a different principle of threshing when compared to other designs which work on the principles of dynamic impact forces to reduce materials [12]. This design works on the principle of abrasion; an application of force axial and radial forces on kernel surface. The conceptual framework was drawn from the operation of a hand-palm and hand-held manual corn shellers (Fig. 1) with a conical configuration and toothed interior, the required force by the operator to thrust, screw or turn and shell the corn progressively was adopted in the development of the machine.
Figure 1. Shelling maize by hand and with a conical sheller.

An axial force is applied by a corn constrictor attached to the lever arm as it presses against the cup-like stationary shelling mechanism which twist the corn in radial direction to detach the grain as it pushes down. The machine has comparative advantages over other methods which include:

1. Less thrust force due to long lever arm,
2. Continuous operation rather than thrusting and reversing as well as
3. Safe operation.

2.2 Methodology

2.2.1 Development of machine

Based on the basic engineering properties of different varieties of maize considered, a hand operated maize sheller shown in Fig. 2 was developed. The machine has an overall dimensions of 30cm×11.5 cm×27cm and consists of a frame, removable metallic shelling unit, collector trays, spring loading mechanism and a lever arm having ring diameter of 2.5cm. A brief description of its components is given below.

Grain collector: The hopper is designed as part of grain collection tray and the shelling cups. The material of construction is mild steel sheet metal, which is readily available in the market at affordable costs. The hopper has the shape of an open drupe truncated at the top, with top having round shape.
Shelling mechanisms: Three different shelling mechanisms were developed as shown in Fig. 3. The mechanisms are conical in shape replica to the geometric shape of corn cob. The upper outer diameter is 71mm while the lower outer diameter is 51mm while the length is 137mm. the internal diameter of the cup is 32mm to accommodate average sized shelled cob.

Figure 3. The shelling mechanisms.

Lever arm: The lever arm is a 26mm diameter and 930mm long mild steel pipe attached to the frame and spring loaded to provide leverage during loading and unloading operations. The cob constrictor is attached to the lever.

Cob constrictor: The cob constrictor is attached to the lever. It has a clamp with which it is attached to the lever, a shot stud connecting the constrictor cap to the clamp.

Helical compression spring: The helical compression spring is a round coil type spring with 70 coils, 27mm outer diameter, 5mm wire diameter, 1mm pitch length and 560mm free length. The spring offers support the lever arm and also provide a stored up potential energy for loading and unloading of the lever feed mechanism.

Main frame: The main frame supports the entire weight of the machine. The total weights carried by the main frame are: weight of the hopper and the threshing chamber; the cob collector and the lever arm. The two design factors considered in determining the material for the frame are weight and strength. Square pipe of dimension 50mmx50mmx20mm and 2mm thickness is used and 1 ½ x 1 ½ x 4mm angle iron was used to give the required rigidity.

2.2.2 Machine performance evaluation criteria

Machine performance was evaluated with respect to the machine capacity, shelling efficiency, and percentage of kernel damage by the following equations expressed by [13].

a. Average number of kernels / cob: The average number of kernels in one cob was determined for 20 randomly selected corn cobs from each sample. The mean values of approximate number of kernels per cob is the product of number of kernel in column and total number of column per cob.

\[ T_k = T_{k,c}xT_c \]  

where \( T_k \) = Total number of kernels per cob; \( T_k \) = Number of kernel in column; \( T_k \) = Total number of column per cob.

b. Shelling capacity: The weight (number) of the maize kernels detached from the cobs in unit time was taken as shelling capacity. It was calculated as:
Shelling capacity \( \frac{\text{kg}}{\text{hr}} \) = \( \frac{\text{Weight of shelled kernels (kg)}}{\text{Time (hr)}} \) \hspace{1cm} (2)

c. Percentage of unshelled grains: This is the ratio of quantity (weight/number) of unshelled of the maize kernels left on the cobs to the total number of kernel input. It was calculated as:

\[
\% \text{ unshelled grains (\%)} = \left( \frac{\text{Weight of unshelled kernels (kg)}}{\text{Total kernel input (kg)}} \right) \times 100 \] \hspace{1cm} (3)

d. Shelling efficiency: This is the percentage by weight of shelled kernels with respect to total kernel input.

\[
\text{Shelling efficiency (\%)} = \left( \frac{\text{Weight of shelled kernels}}{\text{Total kernels input}} \right) \times 100\% \] \hspace{1cm} (4)

Alternatively,

\[
\text{Shelling efficiency (\%)} = 100 - \% \text{ of unshelled kernels} \] \hspace{1cm} (5)

e. Kernel damage percentage: Kernel damage percentage is the ratio of weight or number of damaged kernels to total weight or number of kernel.

\[
\% \text{ kernel damage} = \left( \frac{\text{Weight of damaged grains (kg)}}{\text{Weight of shelled maize kernels (kg)}} \right) \times 100\% \] \hspace{1cm} (6)

3.0 Results and Discussions

3.1 Results

3.1.1 Determination of crop factors

A random sampling of 20 cobs were made from the bulk and their physical properties measured. The samples were further categorized into five samples based on shape and weight factors as tabulated in Table 1.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Diameter</th>
<th>Cob length</th>
<th>Total grain/cob, ( T_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D [mm]</td>
<td>d [mm]</td>
<td>Mean [mm]</td>
</tr>
<tr>
<td>1</td>
<td>28.0</td>
<td>21.3</td>
<td>24.65</td>
</tr>
<tr>
<td>2</td>
<td>26.7</td>
<td>22.2</td>
<td>24.45</td>
</tr>
<tr>
<td>3</td>
<td>26.4</td>
<td>21.5</td>
<td>23.95</td>
</tr>
<tr>
<td>4</td>
<td>28.2</td>
<td>23.1</td>
<td>25.65</td>
</tr>
<tr>
<td>5</td>
<td>23.2</td>
<td>21.2</td>
<td>22.2</td>
</tr>
<tr>
<td>Mean</td>
<td>26.5</td>
<td>21.86</td>
<td>24.18</td>
</tr>
</tbody>
</table>

3.1.2 Machine performance tests results

Three shelling trials (Fig. 4) were conducted using three different shelling mechanisms (raspbar, star and spike tooth) developed and the conventional (finger-palm) method. Local variety of white and yellow maize cobs were used for the experiment at moisture content of approximately 12.6\% (wb). The average numbers of partially shelled kernels, spread kernels, damaged kernels and completely shelled cob were recorded. The collected data were finally analyzed using descriptive statistics.
Table 2 shows the mean of the result of performance tests carried out on the selected cobs using each of the three shelling mechanisms. These were used in the determination of the shelling capacity, percentage of unshelled grains, shelling efficiency and kernel percentage damage of each mechanisms and the overall machine.

**Table 2. Performance tests on machine shelling mechanisms.**

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Total unshelled kernel</th>
<th>Total shelled kernel</th>
<th>weight of shelled kernel [kg]</th>
<th>Total damaged kernel</th>
<th>% of Unshelled Grains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rasp bar</td>
<td>64</td>
<td>296</td>
<td>0.054</td>
<td>0</td>
<td>17.8</td>
</tr>
<tr>
<td>Star</td>
<td>52</td>
<td>354</td>
<td>0.065</td>
<td>3</td>
<td>12.8</td>
</tr>
<tr>
<td>Spike tooth</td>
<td>64</td>
<td>392</td>
<td>0.059</td>
<td>16</td>
<td>14.04</td>
</tr>
</tbody>
</table>

The comparison of the outcome of performance indicators of machine (shelling capacity, percentage of unshelled grains, shelling efficiency and kernel percentage damage) and the conventional finger-palm method was presented in Table 3.
Table 3. Comparison between conventional and maize sheller.

<table>
<thead>
<tr>
<th>Shelling methods</th>
<th>Trials</th>
<th>Time taken [min]</th>
<th>Shelling capacity [kg/hr]</th>
<th>Shelling efficiency [%]</th>
<th>% kernel damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional (Finger-palm)</td>
<td>1</td>
<td>0.53</td>
<td>12.40</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.42</td>
<td>15.34</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.30</td>
<td>13.75</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td><strong>Mean performance</strong></td>
<td>0.42</td>
<td><strong>13.83</strong></td>
<td>100</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Shelling mechanisms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rasp bar</td>
<td></td>
<td>0.20</td>
<td>16.2</td>
<td>82.22</td>
<td>0.00</td>
</tr>
<tr>
<td>Star tooth</td>
<td></td>
<td>0.15</td>
<td>26.0</td>
<td>87.19</td>
<td>0.74</td>
</tr>
<tr>
<td>Spike tooth</td>
<td></td>
<td>0.18</td>
<td>19.67</td>
<td>85.97</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Mean performance</strong></td>
<td>0.18</td>
<td><strong>20.62</strong></td>
<td><strong>85.13</strong></td>
<td></td>
<td><strong>1.25</strong></td>
</tr>
</tbody>
</table>

3.2 Discussions

Shelling capacity: During conventional method of shelling, there are inconveniences such as pains, sores on thumb etc. The mean kernel shelling capacity using hand maize sheller was 20.62 kg/hr while the kernel mean shelling capacity using conventional shelling method was 13.83 kg/hr.

Shelling efficiency: The mean shelling efficiency of sheller was 85.13%. The star tooth mechanism has a better efficiency 87.19% in performance than rasp 82.22% and spike tooth 85.97%. A 100% shelling efficiency was attained using conventional finger-palm method.

Kernel damage: The developed hand maize sheller detached the kernels from cobs with visible kernel damage of 0.74% and 0.51% for star and spike tooth mechanisms respectively. Conventional shelling method recorded a zero % kernel damage. This is obvious as a result of lesser effort and no impact of any kind.

Overall machine performance: The machine overall performance is favourable with 20.62kg/hr shelling capacity, 85.13% shelling efficiency and 2.13% kernel damage. The mean kernel damage is higher because of the spike tooth performance.

Cost valuation

For cost evaluation purposes, table 4 presents a bill of engineering measurement and evaluation (BEME) for the cost list of material of this project modification and possible construction or fabrication of this design’s hand operated maize threshing machine.

Table 4. Bill of engineering measurement and evaluation.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Cost (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sheet metal</td>
<td>16 gauge mild steel sheet</td>
<td>¼</td>
<td>1,500.00</td>
</tr>
<tr>
<td>2</td>
<td>Bolts and nuts</td>
<td>M10, M13</td>
<td>6pcs</td>
<td>600.00</td>
</tr>
<tr>
<td>3</td>
<td>Lever arm</td>
<td>Pipe, mild steel (OD,40mm L,730mm)</td>
<td>2pcs</td>
<td>1,500.00</td>
</tr>
<tr>
<td>4</td>
<td>Handle</td>
<td>round pipe</td>
<td>1pcs</td>
<td>1,000.00</td>
</tr>
<tr>
<td>5</td>
<td>Shelling unit</td>
<td>Shelling cups</td>
<td>1pc</td>
<td>500.00</td>
</tr>
<tr>
<td>6</td>
<td>Collector</td>
<td>Construction</td>
<td>1pc</td>
<td>1,000.00</td>
</tr>
<tr>
<td>7</td>
<td>Labour</td>
<td>-</td>
<td>-</td>
<td>5000.00</td>
</tr>
<tr>
<td>8</td>
<td>Contingencies</td>
<td>-</td>
<td>-</td>
<td>200.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td><strong>13,100.00</strong></td>
</tr>
</tbody>
</table>
4. Conclusion

Based on the overall objectives of the project, a hand operated maize sheller, had been successfully developed and constructed using locally available materials. The machine is simple in operation, less bulky with good ergonomic considerations for its comfortable use in a standing/sitting posture by either male or female operator. This is justified by the portability and low height of 0.5 m as well as the low energy requirement.

The machine overall performance is favourable with 20.62kg/hr shelling capacity, 85.13% shelling efficiency and 2.13% kernel damage. The mean kernel damage is higher because of the spike tooth performance, whereas for conventional method it was 12.63 kg/hr and 100% and zero % respectively.

Comparing the three shelling mechanisms, the star mechanism has a better shelling capacity (26.0kg/hr). The level of visible grain damage to the detached kernels recorded by both methods marginally exceeds the (0.2%) standard for quality maize in terms of damaged kernels [9, 13]. Thus the sheller seems to ease shelling maize for household use and consumption.

The conventional finger- palm method attained a 100% shelling efficiency and zero % kernel damage with lower mean kernel shelling capacity of 13.83 kg/hr. In comparison with conventional shelling method, the hand operated sheller has a better output capacity, reasonable shelling efficiency but slightly higher kernel damage. By implication, machine performance efficiency does not give a true reflection of how effective a system work until the machine capacity is determined.

Future Works

The star and spike tooth mechanisms be modified to reduce kernel damage.

Conflict of Interest

The authors declare that there is no conflict of interest.

References


