Nepal Engineers' Association, Gandaki Province, Technical Journal

Design and Fabrication of a Spiked-Shaft Maize Seed Separator

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Received: January 18,2023; Revised: April 01, 2023; Accepted: July 12, 2023

Abstract

Maize shelling in developing and underdeveloped nations has been & remains a severe problem to its processing as it is tedious and requires more labour hours. This study aims to design and fabricate a motor-powered spike-shaft type Maize Seed Separator (MSS) machine. The design and selection of components like the motor, belt, frame, bearing, and shaft were made based on general design considerations. After the complete fabrication of the MSS machine, it was tested to find its shelling capacity and efficiency. The shelling capacity was found to be 220 kg/hr, which is 80 times faster than manual shelling and the maximum shelling efficiency was found to be 97 % at the feeding rate of 4 kg at a time. The machine consumes 1.28 kW of electricity, which, when operated for one hour, would cost about Rs. 14 per hour.

Keywords: *Shelling Capacity, Shelling Efficiency, Spiked-Shaft*

1. Introduction

Maize is the predominant cereal of the world, with 1,016 MMT produced on 184 million ha globally (FAOSTAT, 2013). Cultivated in an area of around 891583 ha, maize is among the dominant crops in Nepal. In the hills of Nepal, it is traditionally cultivated for food, feed, and fodder. In low-lying river basins and the Terai, where maize is typically produced, it is also grown in winter and spring. Over the past few decades, maize demand has increased by roughly 5% annually (Sapkota & Pokhrel, 2010). In Nepal, 98g of maize was consumed daily per person in 2015 (KC et al., 2015). In Nepal, 2,231,517 tonnes of maize were produced overall, yielding 2.50 tonnes per hectare. Figure 1 illustrates Nepal's maize production in 2020, which was 2,720 thousand tonnes. The output of maize in Nepal increased significantly over the previous 50 years, going from 761 to 2,720 thousand tonnes at an increasing yearly rate that peaked at 34.12% in 1980 and then declined to 2.64% in 2020 (World Data Atlas, Knoema, 2021).

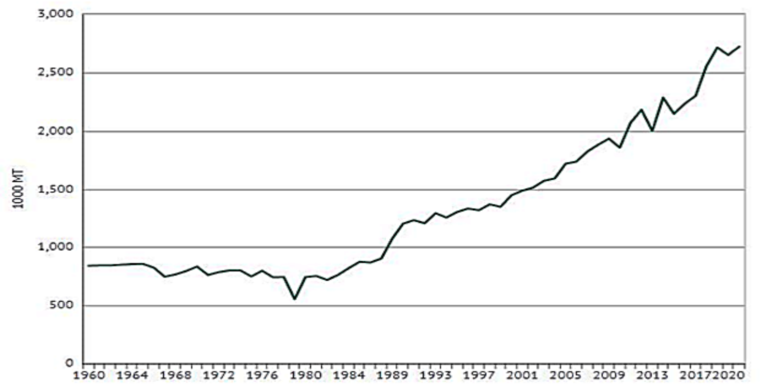


Figure 1: Trend of Maize Production in Nepal

1.1 Literature Review

Yu et al. (2021) analysed the optimal performance of maize thresher with spiked teeth. They studied the effect of the width of the threshing component and drum RPM using simulation on self-developed software and then verified the results experimentally. They found that the increase in drum RPM increased both kernel damage rate and threshing rate. However, as the width of the threshing component was increased, the threshing rate increased, and the damage rate decreased until the stacking between adjacent components affected the threshing rate. The optimal thresher performance was recorded when the threshing component's width was 25 mm at 187.50 RPM with 98.04% shelling efficiency and 2.56% kernel damage rate.

Chilakpu et al. (2018) fabricated a maize sheller with a spiked shaft containing integrated blowers. They fed maize at 12% moisture content into the machine and reported a 650kg/hr output. They used a spiked shaft of length 1100mm and 30mm diameter. Similarly, they reported an air velocity of 10.5m/s to blow away the maize chaffs. They started from air velocity equal to the terminal velocity of maize, equal to 13.85 m/s (Ghafori et al., 2011), and adjusted until a satisfactory result was obtained.

Sharawy et al. (2017) evaluated a corn Sheller with a spiked tooth cylinder at different rotational speeds and moisture content. They noted that increasing the cylinder's speed increased the shelling performance and the proportion of grains that were broken. They concluded that the shelling machine gave the best productivity and shelling efficiency when it was run at 120 RPM, and the corn had a moisture content of 12%.

Hand-threshing seems to be the preferred method of shelling maize among small-scale farmers. Mali et al. (2015) observed that although the sheller machines working on diesel and petrol engines have been developed, they are not viable for these farmers due to their high cost. Therefore, there is a need for a low-cost threshing machine.

Darudkar & Handa (2015) found out that marginalised and small-scale farmers in developing countries either pay separately for shelling by going to shelling industries or they directly sell their unshelled corn to vendors. Both of these methods are unprofitable for the farmers because in the former extra costs are incurred during transportation and use of the shelling services, whereas in the latter, the vendor buys the unshelled corn at a lower price and takes up most of the profit. Therefore, to uplift the farmer's economic status, they concluded that there is a need for an intermediate technology to mechanise the corn shelling process.

Aremu et al. (2015) also used spiked cylinders for their shelling machine. They used three pulleys to vary the shaft shelling speed from 623 RPM to 823 RPM to 886 RPM. They also used three samples of varying moisture content, viz. 13%, 15% and 17%, respectively. They reported the highest shelling speed and efficiency at 13% moisture and 886 RPM. The output was reported to be 623.99kg/hr. They used 47 spikes on a shelling drum of 750mm in length and diameter of 92mm.

Karikatti and Satish (2015) reported on the difference between crank-operated crank sheller and hand shelling. They reported 2.78 kg/hr data for hand shelling and 5.56 for crank shelling.

Different types of cylinders have been used in maize threshing machines. Most notably, corrugated cylinders and spiked tooth cylinders. However, a spiked tooth cylinder seems to offer certain advantages. For example, Oriaku et al. (2014) noted that a spiked tooth cylinder offers a higher feeding rate than rasp-bar cylinders. They used a 20kg sample of corn with a moisture of 15.14% and reported an average threshing time of 2.95 minutes. This result was achieved by a machine where the length and diameter of the de-cobbing barrel were 0.95m and 0.21m, respectively.

Ghadi & P (2014) also used a similar technique for threshing and obtained an output of 45 kg/hr. Their machine had an outer barrel diameter of 304 mm and a length of 720mm.

One might be concerned about the effects of motorised shelling on the germinability of the maize kernel. Pandey et al. (2013) compared hand-threshing and mechanised threshing processes regarding germination and embryo damage. They concluded that mechanised corn Sheller is equally efficient to hand shelling in these aspects.

Budynas and Nisbett (2010) have detailed the design considerations for pulleys, shafts, and bearings. They have also listed all the required design equations in detail.

In this study, a Maize Seed Separator Machine was designed, fabricated, and tested using locally available resources.

1.2 Working Principle

The threshing of the maize seed in the proposed machine is done uniquely compared to other methods. At first, the kernels are dropped into the drum through the inlet hopper via gravitational dropping. Then, the spikes attached to the shaft, driven by a motor, cause the individual maize seeds to separate from the cob due to the impact created by the spikes. The separated maize seeds fall through the holes made in the drum and reach the outlet of the machine. When the hinged door is opened, the cobs are finally released from the drum. The attached blower removes chaff from the seeds before collection.

An electrical motor powers the machine. The mechanical power from the motor is ultimately transmitted to the load and the blower via a belt-pulley mechanism.

2. Methodology

Each component of the machine was designed as per the general design considerations. Design dimensions were extracted and CAD models of each component were generated in Solidworks Software. The machine was fabricated and then tested based on the available materials to assess its performance.

2.1 Design Considerations

The MSS machine's design consists of the belt, pulley, shaft, frame, bearings, and selection of motors. These design considerations are discussed as follows:

2.1.1 Selection of Motor

For the selection of the motor, the following assumptions about the spikes were made:

a) Spike Dimensions (l*b*h) = 20cm*2.5cm*0.2cm
b) The density of spike material, i.e., mild steel (ρ) = 7840kg/m^3
c) No of spikes on the cylinder(n) = 10

Using the relation for mass as:

$$M = l * b * h * \rho \tag{2.1}$$

The mass of each spike was calculated to be 0.078 kg. The safe RPM value was surmised to be 350 RPM. This RPM gave an angular velocity (w) of 36.65 rad/s and a linear velocity (v) of 7.69 m/s. The work done on the maize is due to the centrifugal force of the spike on the maize. So, the total centrifugal force of all ten spikes rotating at 350 RPM was calculated from the following relation:

$$F_c = \frac{mv^2n}{l} \tag{2.2}$$

Plugging the values of m, v, n, and l, the total centrifugal force was 231 N. Assuming a pulley radius (R) of 6 inches for the driven pulley and using the relation in 2.3, the torque required on the driven pulley equalled 35N-m.

$$T_1 = F_c * R \tag{2.3}$$

Using the power relation for a motor as given in equation 2.4, the power required to rotate the shaft as P = 1282 W was obtained, equivalent to around 1.72 HP. So, a standard single-phase motor of 1440 RPM and 2 HP was taken. For the required RPM of 350, the pulley diameter for the motor was chosen accordingly.

$$P = \frac{2\pi N_1 T_1}{60} \tag{2.4}$$

2.1.2 Design of Belt

The larger angle of contact for an open belt pulley is given as follows:

$$\theta_L = \pi + 2 * \sin^{-1}\left(\frac{d_1 - d_2}{2C}\right) \tag{2.5}$$

Here 'd_1' and 'd_2' are the diameters of the driver and driven pulleys. Similarly, 'C' is the central distance between the pulleys and 'θ'$_L$ is the larger angle of contact in radians. Likewise, the smaller angle of contact is calculated as follows:

$$\theta_S = \pi - 2 * \sin^{-1}\left(\frac{d_1 - d_2}{2C}\right) \tag{2.6}$$

Where θ_s is the smaller angle of contact in radians. Finally, the length of the belt is found by:

$$L = \sqrt{4C^2 - (d_1 - d_2)^2} + \frac{(d_1 * \theta_L + d_2 * \theta_S)}{2} \tag{2.7}$$

Table 1: Design of Belts

Transmission between the motor and shaft		Transmission between Shaft and Propeller	
Parameters	Using Eqn 2.5, 2.6, 2.7	Parameters	Using Eqn 2.5, 2.6, 2.7
d_1 = 76.2 mm	θ_L = 3.61 radians	d_1 = 76.2 mm	θ_L = 3.23 radians
d_2 = 304.8 mm	θ_S = 2.67 radians	d_2 = 152.4 mm	θ_S = 3.05 radians
C = 490 mm	L = 1604.85	C = 850 mm	L = 2039.28 mm
Choice : Polyamide V-Belt of 63 in.		Choice: Polyamide V-belt of 81 in.	

2.1.3 Design of Frame

The frame experiences buckling due to the weight of the machine. It is assumed to be fixed in the middle and at both ends and also for buckling in a plane orthogonal to the vertical plane. Similarly, the links are assumed to be hinged in the middle for buckling in the vertical plane.

2.1.4 Selection of Bearing

To reduce the friction between rotating surfaces, ball or roller bearings are used. The ball and roller bearing contain an inner race connected to the shaft and an outer race carried by the mounting. In the design, ball bearings were selected because:

a) Ball bearings reduce friction appreciably over the roller bearings
b) Less repair and replacement are required due to their reliability and excellent power-saving properties

The bearing's equivalent load is defined as the radial or axial load that, if applied, would produce the same total permanent deformation at the most stressed ball or roller as occurs under the actual loading state.

The equivalent load on the bearing is defined as:

$$F_{eq} = X * V * F_r + Y * F_a \tag{2.8}$$

The construction and geometry of the specific bearing govern the X and Y factors.

For 90% reliability dynamic load rating is:

$$C_{10} = F_D \left[\frac{X_D}{X_0 + (\theta - X_0)(1 - R_D)^{\frac{1}{b}}} \right]^{\frac{1}{a}} \tag{2.9}$$

For ball bearing a=3.

$$X_d = \frac{(60 * L_D * N_D)}{10^6} \tag{2.10}$$

L_D is the desired life of the bearing in hours, and N_d is the desired working speed of the bearing. The design will be selected if the load rating is greater than the equivalent load. Desired life is assumed to be 5000 hours, and the operating speed of 350 RPM is taken. The maximum radial load of 551N (weight of shaft + required centrifugal force) is assumed by adding all the radial loads and a reliability of 95%. So, from equations 2.9 and 2.10, it is obtained that X_d = 105 and C_{10} = 3.067 KN. According to these results, a 02-20 series deep groove ball bearing with a bore of 25mm can be safely used.

2.1.5 Design of Shaft

A shaft diameter of 25mm was first selected. Therefore, the maximum safe load on the shaft is calculated as follows:

$$d^3 = \frac{16}{\tau * \pi} * \sqrt{(M_b^2 + T_2^2)} \tag{2.11}$$

The ultimate stress for mild steel is 265 MPa. Using the factor of safety of 1.5 in 2.12, the shear stress τ is obtained equal to 83.33 N/mm^2.

$$\tau = \frac{Ultimate\ stress}{Factor\ of\ safety * 2} \tag{2.12}$$

The shaft length(L) is 84 cm, and it is subjected to torsional stresses and bending moment. As a result, the bending is given by:

$$M_b = F_s * L/4 \tag{2.13}$$

Using the values of torque, safe load, and diameter in 2.11, the bending moment is calculated to be 253246N-mm. From 2.13, this gives a safe load of 1206N. Furthermore, the centrifugal force experienced by the shaft is 231N, as seen from equation 2.2. Therefore, the shaft diameter is safe.

2.2 Modelling, Assembly, and Fabrication

2.2.1 Modelling Procedures

The modelling of the parts, such as the Frame, Drum, Spiked Shaft, Hopper, Sliding Door, etc., was done in SolidWorks 2019. The individual parts were modelled separately and then assembled, whereas the model of the motor and the bearings were imported.

2.3 Fabrication

After the completion of CAD modelling of the components in Solidworks software, a few parts were procured from vendors. These include the bearings, belt and pulleys, and fan. In contrast, the remaining components, such as the shaft, frame, and drum, were fabricated in the workshop and assembled. A lathe was used to machine the shaft. First, the suitable length of a mild steel blank was cut. Facing and turning operations were performed on it to obtain the desired geometry. Then, flat pieces of mild steel rods were cut and welded on the shaft. A welding operation was also carried out to create the frame. Mild steel bars of appropriate lengths were cut and welded together to make a sturdy frame. The drum, hopper, and ramp were made using a GI sheet. The drum was welded firmly on the frame and the shaft was supported on two ends of the frame using bearings.

2.4 Testing of the Machine

After the complete fabrication of the MSS machine, testing was performed to determine the shelling capacity and efficiency. First, a sample of maize was loaded onto the hopper and the sliding door was opened. After securing the sliding door again, the motor was turned on for a specific interval and the maize sample were checked to see if they were satisfactorily threshed. If found unthreshed, the machine was operated again and the procedure was repeated. The time required was noted and the remaining cobs on a barrel were collected. The unshelled kernels were then hand-shelled. The shelled and unshelled kernels were weighed separately. The damaged kernels were identified, separated, and weighed.

After the observations, different efficiencies were calculated using the following equations:

$$\text{Shelling Capacity} = \frac{Shelled\ Kernels\ (kg)}{Time\ Taken(Sec)} \tag{2.35}$$

$$\text{Shelling Efficiency} = \frac{weight\ of\ shelled\ kernels(kg)*100\%}{Total\ kernels\ weight(kg)} \tag{2.16}$$

$$\text{Kernel Damage} = \frac{Damaged\ kernels(kg)*100\%}{Shelled\ Kernels(kg)} \tag{2.17}$$

Similarly, the total average threshing rate of the machine can be determined as follows:

$$Threshing\ Rate(\frac{kg}{hr}) = Sample\ Weight * No.of\ Operation\ Cycles \tag{2.18}$$

3. Results and Discussion

3.1 Design

All the drawings below follow a third-angle orthographic projection. They were derived from the models prepared in Solidworks and were utilised as references during the fabrication procedure.

3.1.1 Frame

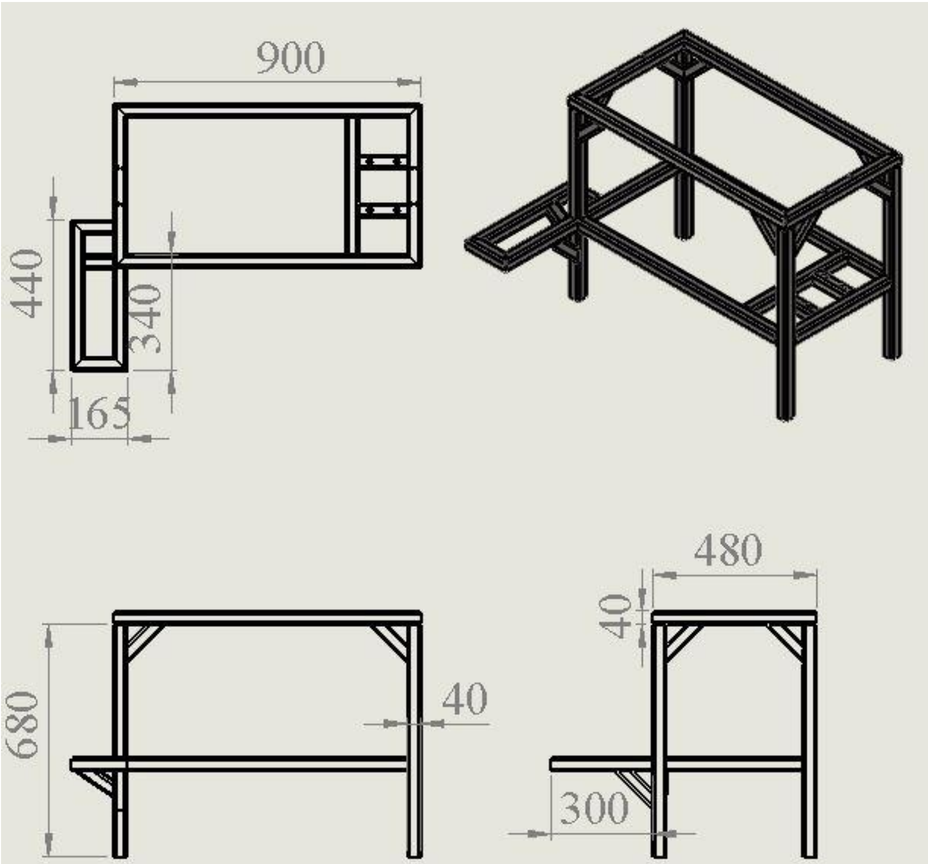


Figure 2: Frame

3.1.2 Drum

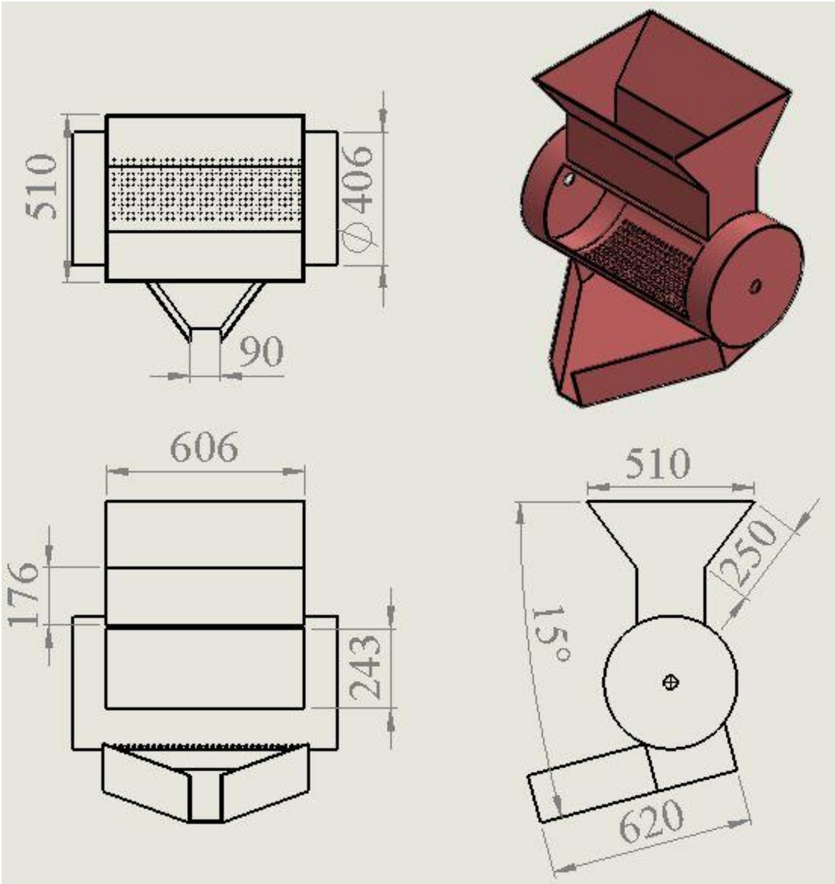


Figure 3: Different Views of Cylindrical Drum

3.1.3 Spiked Shaft

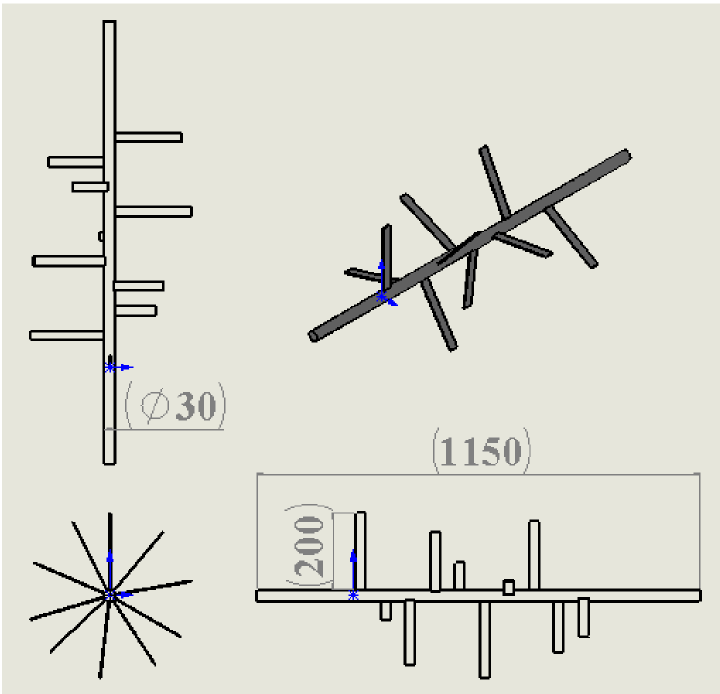
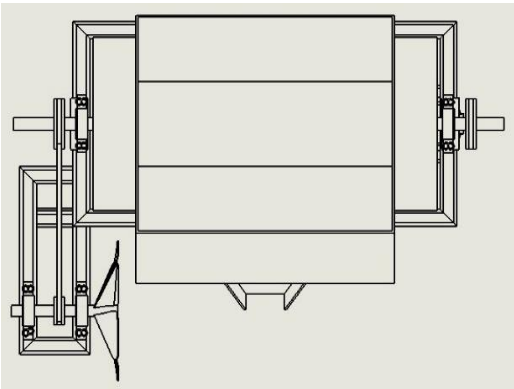


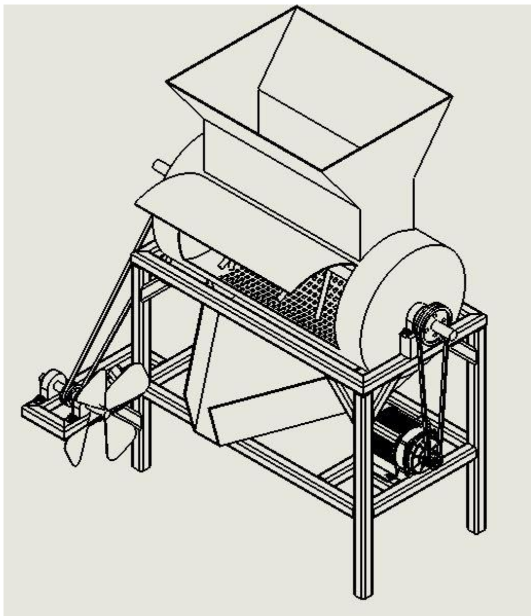
Figure 4: Spiked Shaft

3.2 Assembly and Fabrication

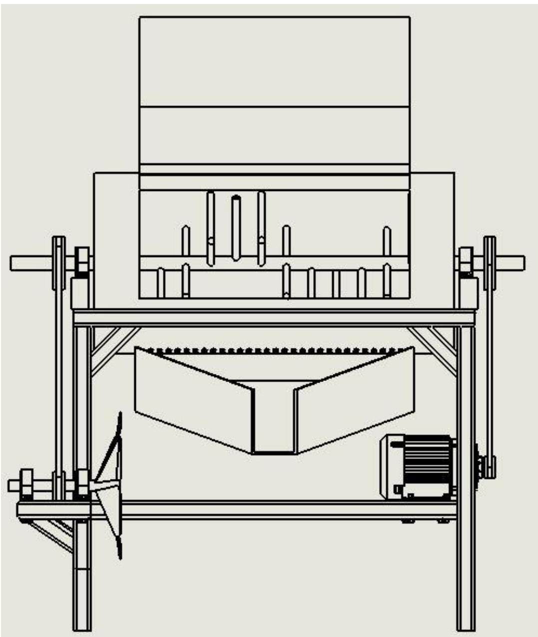
Figure 5 illustrates the different views of the fully assembled machine. Figure 6 presents a rendered model prepared before the fabrication, and finally, figure 7 shows the fully fabricated machine.



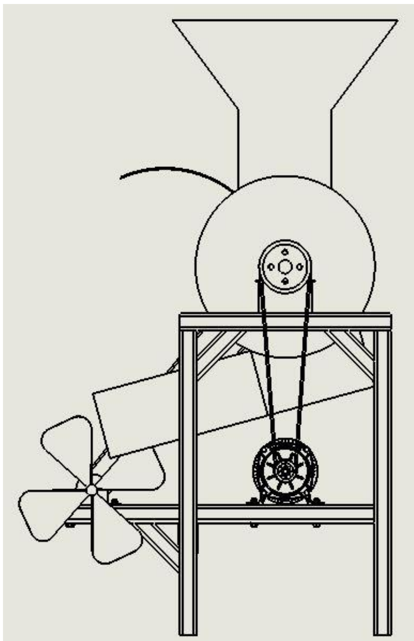
Top View



Isometric View



Front View



Side View

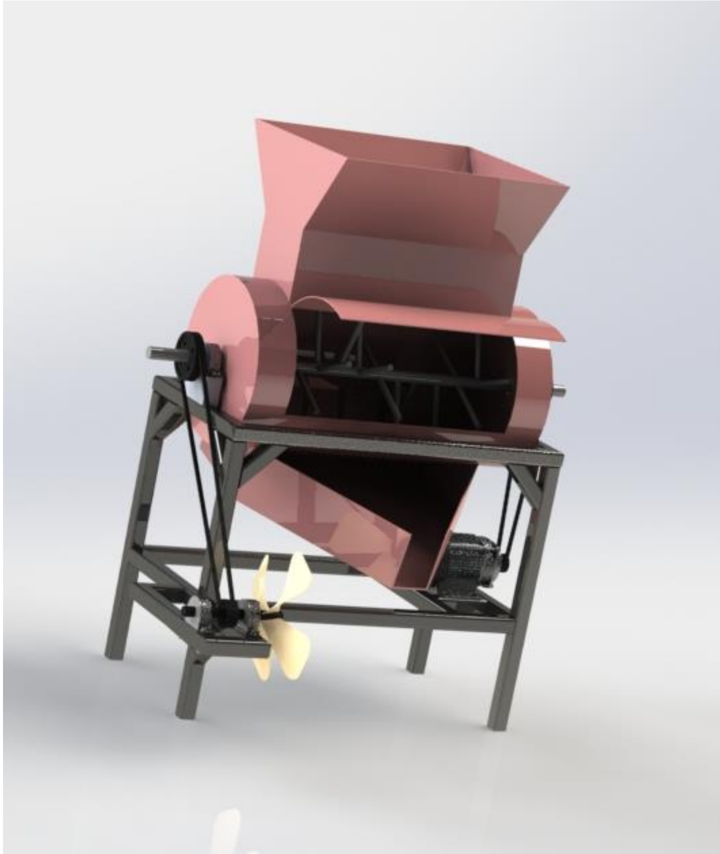


Figure 6: Rendered Photo of Assembled Machine

Figure 7: Side View of the Fabricated Machine

3.3 Observations

The observations for different sample weights are listed in Table 2. The tests were performed as mentioned in 2.4.

Table 2: Observation Details

S.N.	Sample(kg)	Duration (sec)	Total Kernels (kg)	Unshelled Kernels (gm)	Damaged Kernels (gm)
1	2.4	3	2.2	66 (3%)	60 (2.7%)
2	2.5	3.5	2.4	62 (2.6%)	60 (2.5%)
3	3.0	4	2.3	68 (2.8%)	67 (2.8%)
4	3.1	4.5	2.37	59 (2.5%)	70 (2.9%)
5	4	5	3.4	73 (3%)	75 (2.2%)

Table 2 shows that the shelling efficiency and kernel damage up to a sample size of 4 kg is acceptable. The observation is shown graphically in figure 8. While using a sample of 5 kg, the machine jammed and did not perform satisfactorily. Therefore, the optimum sample size was determined to be 4 kg.

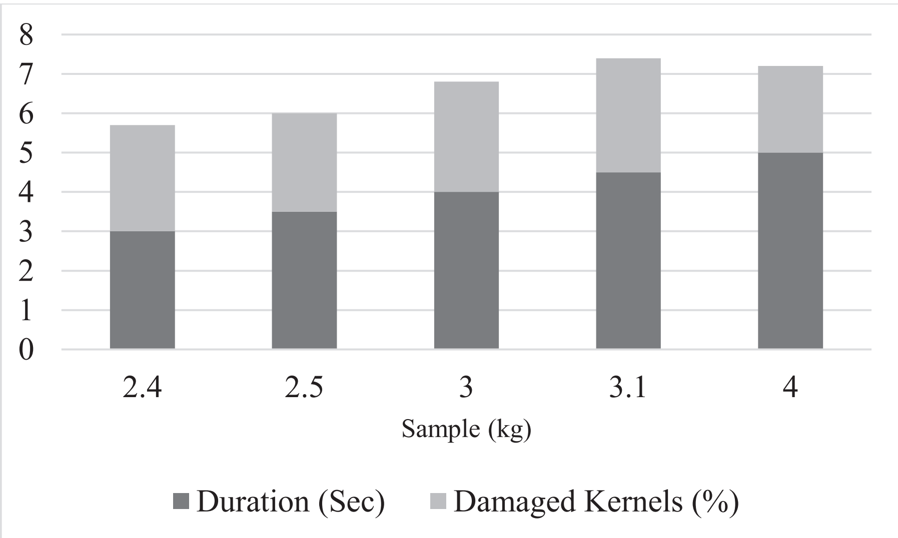


Figure 8: Damaged Kernels at Different Feeding Rates

One operation cycle of the machine consists of all the activities from loading the maize sample to collecting the maize kernels. Based on the observations, for a 4 kg maize sample, one operation cycle took an average of 65 seconds, including the shelling time. Therefore, around 55 operation cycles can be performed in one hour. For a sample size of 4 kg, the obtained values are shown in Table 3.

Table 3: Observed Values for Optimum Sample Size

Particulars	Observed Values
Sample Size	4 Kg
Threshing Rate	220 kg/hr
Shelling Efficiency	97 %
Kernel Damage	3 %

From the torque and RPM requirements stated in section 2, the machine's power consumption was calculated to be 1.28 kWh of electricity. This energy is equivalent to operating a 1200W heater for one hour.

From the literature review, the manual shelling rate for maize was found to be 2.7 kg/hr, and from the testing, the output rate for the fabricated MSS machine was calculated to be 220 kg/hr. Therefore, the machine was around 80 times more productive than manual shelling.

4. Conclusions

Based on the fabricated MSS machine and its performance, the general objective of fabricating an agricultural maize seed separator machine with locally available resources is fulfilled. Furthermore, as seen from the test values, the MSS machine was efficient in terms of its threshing capacity, Shelling capacity, and Shelling efficiency while minimising kernel damage. The machine is easy to use and doesn't need highly specialised labour. It might be a good solution for small farmers because it is cheaper than current thresher machines. The machine consumes 1.28 kW of electricity, which, when operated for one hour, would cost about Rs. 14 per hour.

The MSS machine was found to be 80 times more effective than hand-shelling. However, the machine jammed with a sample size greater than 5 Kg. Also, the noise and vibration generated by the machine were significant. Hence, future research on alternative designs and modal analysis could be carried out to yield more efficient machines.

Acknowledgement

We gratefully thank the staff and faculties at the Department of Mechanical and Automobile Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, for their constant guidance and support.

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