



DESIGN AND FABRICATION OF A CANVAS BELT THRESHER FOR EFFICIENT COWPEA THRESHING

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ABSTRACT

The increasing demand for efficient and cost-effective cowpea threshing machinery led to the development of a canvas belt thresher. This study focuses on the design and fabrication of a thresher that minimizes grain damage while enhancing threshing efficiency. The machine was constructed using mild steel iron, 22-gauge sheet metal, and canvas materials, ensuring robustness and cost-effectiveness. The total production cost of the machine was ₦253,000, making it affordable for small-scale farmers. The canvas belt system, selected for its rubbing action, was designed to improve grain separation and reduce kernel bruising compared to traditional impact-based mechanisms. Key design considerations included material selection, power transmission, shaft design, and motor capacity to ensure durability, ease of use, and affordability. A 3.18kW gasoline engine powered the thresher, enabling both field and off-field operations. Performance results showed that the machine (1500mm × 800mm × 820mm) operates between 400 to 1200 rpm of drum speed, yielding a high level of efficiency with minimal grain loss and damage. This machine offers a reliable solution for small-scale farmers, significantly reducing labor, time, and operational costs associated with cowpea threshing.

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1.0 Introduction

Threshing is a critical post-harvest operation in crop production, aimed at separating grains from harvested crops with minimal loss or damage. Efficient threshing ensures grains retain their quality, market value, and shelf life. However, conventional threshing methods often lead to significant grain losses, including broken grains, un-threshed grains, and spilled grains. According to the Bureau of Indian Standards, total grain loss during threshing should not exceed 5%, with broken grains limited to less than 2% (Clark, 2007; BIS, 1985). These standards underscore the need for efficient threshing mechanisms to safeguard grain quality and market value. Many existing threshing machines employ drum, spike-tooth, or rasp-bar mechanisms, which rely on impact-based threshing. While effective for grain separation, the high impact forces associated with these mechanisms often damage kernels, causing bruises, splits, and shattering. This damage reduces the grains' market value and shortens their storage life (Clark, 2007). To address these limitations, researchers have explored alternative threshing methods that prioritize grain integrity. Fernando and Hanna (2005), for instance, developed soybean threshing mechanisms that minimized kernel damage using a specially designed threshing chamber and pneumatic systems. Similarly, Fernando *et al.*, (2004) introduced a soybean harvesting and threshing unit that processed pods while still rooted, thereby reducing kernel damage and improving operational efficiency. Gelaw (2020) advanced this work by investigating the theoretical and experimental aspects of threshing mechanisms for tef (*Eragrostis tef*), focusing on its engineering properties. Gelaw designed a threshing unit that minimized grain damage while maintaining high efficiency. El-Shal *et al.*, (2020) developed a rubbing-based thresher for seed crops like flax and sunflower, significantly reducing seed damage and improving threshing efficiency. Istifanus *et al.*, (2022) evaluated a cereal crop thresher modified to incorporate rubbing actions, achieving higher efficiency and reduced grain damage compared to traditional impact-based designs. These studies collectively demonstrate the advantages of adopting rubbing-based mechanisms to preserve grain quality and extend storage life.

Despite these promising developments, the application of rubbing action to cowpea threshing remains limited. Allen and Watts (1998) developed a belt thresher for cowpea beans, but its complexity, high power consumption, and cost made it impractical for small-scale farmers. Chen *et al.* (2025) introduced a low-damage threshing drum for corn, combining rubbing and impact actions to reduce kernel breakage—a concept that could potentially be adapted for cowpea threshing. While most designs, such as those by Ojomo *et al.* (2010), Maunde (2011), and Fawohunre and Olajide (2020), continue to rely on impact-based mechanisms, the advantages of rubbing actions highlight their potential for minimizing grain damage and enhancing threshing efficiency. This study aims to design and fabricate a cost-effective and efficient canvas belt thresher for cowpea threshing, leveraging rubbing action to address challenges related to grain damage and affordability. Upon completion, the proposed machine will provide small-scale farmers with a reliable and sustainable threshing solution, reducing labor intensity, operational costs, and time requirements while preserving grain quality.

2. Materials and Method

2.1 Materials Selection

Machine members experience stresses that affect performance and service life, making material selection a critical aspect of the design process. For the thresher, 22-gauge sheet metal was used for the tray, chute, and blower components, while a semi-rough canvas belt (400 x 4000 mm) was resized for threshing. A 2m long, 70mm diameter galvanized steel pipe served as the conveyor drum, and a 3.5m mild steel rod (20mm diameter) was selected for the shaft. Twelve radial bearings with a 20mm internal diameter were used, along with a frame constructed from 45x45mm angle iron. An 'A' type V-belt, bolts, nuts, and welded joints were employed for assembly, with a gasoline engine providing power for both field and off-field operations. Additional materials like cutter blades, welding electrodes, and other hand tools were also utilized.

2.2 Design considerations

In designing the thresher, key considerations include: weight and space limitations to ensure it is both movable and stable, while remaining compact for operation and storage. The clearance between the thresher belts was optimized for efficient threshing without bruising the grains. Locally sourced materials were chosen to ensure easy replacement and simple fabrication techniques. The machine was designed for ease of operation, allowing a wide range of users, while also prioritizing operator safety by positioning movable parts away from the user. Reliability and cost-effectiveness were also considered, using affordable, locally available materials to make the machine accessible to cowpea farmers. Aesthetics were also factored in to make the machine visually appealing.

2.3 Methods

2.3.1 Design Analysis and Calculations

To ensure cost-effectiveness and efficiency, calculations and selections were performed to create a functional machine using standard references, tables, and charts.

2.3.1.1 Thresher Drum Diameter

The drum diameter is calculated using Kutte's (2001) formula, yielding a diameter of 0.07m for a peripheral velocity of 14m/s and a cylinder speed of 550rpm.

2.3.1.2 Thresher Belt Clearance and Thresher Belt Capacity

Based on the cowpea pod size, the belt clearance was set between 6.1mm and 7.32mm, adjustable for effective threshing depending on seed size and moisture content. This was based on Allen and Watts (1998) where clearance should be between 50 – 60% of the length of the grain. Simulations indicated a lower belt length of 1.1m and a top belt length of 0.84m (Allen, 1993 in Allen and Watts, 1998). The belt speed for design purposes was set at 2m/s, giving a calculated belt capacity of 6.4 kg/s (Daniyan *et al.*, 2014; Sousa *et al.*, 2015).

2.3.1.3 Power to Drive Thresher Belt and V-Belt Selection

Using the frictional angle of cowpea pods (44°), the power required to thresh is 1.63kW, adjusted to 1.81kW with a service factor of 0.9. The force needed to separate the cowpea from the pod was calculated as 1.94N, ensuring it stays below the shear force threshold to avoid damaging the seeds (Khurmi and Gupta, 2006). V-belts were chosen for power transmission due to their better grip, ease of installation, and smaller pulley diameter requirements. The allowable power transmission for the belt was calculated at 1.58kW, confirming the use of an A-type V-belt with a 130mm pulley (Bhandari, 2010).

2.3.1.4 V-Belt Pulley Parameters

The calculation of V-belt pulley parameters involves determining essential values such as center distance, pulley diameters, velocity ratios, and belt lengths (Figure 1). Key steps include:

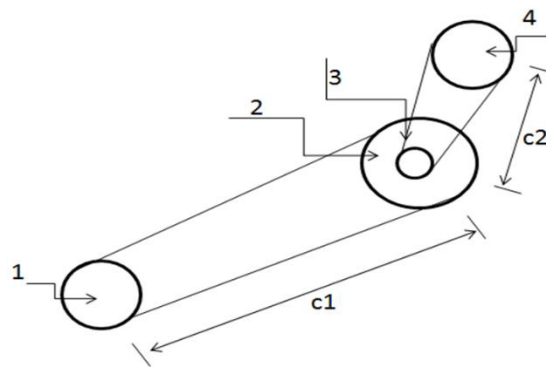


Figure 1: V-belt and pulley arrangement where 1) is motor pulley, 2) thresher drive pulley, 3) extension pulley and 4) the thresher driven pulley.

1. Angular Speed of Shafts: The input shaft's angular speed (ω_1) is calculated using the formula $\omega_1 = (2\pi N_1)/60$, where N_1 is 1500 rpm, resulting in $\omega_1 = 157.1$ rad/s. Similarly, for the output/thresher shaft, $\omega_2 = (2\pi N_2)/60$, with $N_2 = 550$ rpm, resulting in $\omega_2 = 57.6$ rad/s.

2. Velocity Ratio: The velocity ratio (I) is derived as $N_1/N_2 = d_2/d_1$. With $N_1 = 1500$ rpm and $N_2 = 550$ rpm, the ratio is $I = 2.73$. Given a pulley diameter $d_2 = 130$ mm, d_1 is calculated as 50mm (standard).

3. Pulley Diameters: For the thresher belts, a speed reduction of 5:2 is chosen for differential speeds. With a 70mm diameter pulley for d_3 , d_4 is calculated as 170mm (standard) based on the ratio.

4. Center Distance Between Pulleys: The distance between pulleys is calculated as (Khurmi & Gupta, 2006):

- For d_1 and d_2 : $D_1 = 283$ mm, $D_2 = 1600$ mm, $C_1 = 650.314$ mm.
- For d_3 and d_4 : $D_1 = 377$ mm, $D_2 = 2500$ mm, $C_2 = 200.02$ mm.

5. Belt Length: The belt lengths are calculated as:

- For d_1 and d_2 , $L_1 = 1600$ mm (standard).
- For d_3 and d_4 , $L_2 = 800$ mm (standard).

These parameters ensure the proper design and functioning of the V-belt pulley system.

2.3.1.5 Determination of Angular Speed of Shafts

The angular speed of the input shaft (ω_1) is calculated using the formula in equation (1) (Khurmi & Gupta, 2006):

$$\omega_1 = \frac{2\pi N_1}{60} \tag{1}$$

$$= \frac{31.4}{0.065} = 483 \text{ N}$$

The tension on the belt responsible for threshing can be shown in Figure 2. Tension on the slack side (F_2), is determined by equation (2) as follows:

$$F_2 = \frac{F_1}{3} \tag{2}$$

$$= \frac{483}{3} = 161 \text{ N}$$

The resultant tension (F_e) is then (Equation. 3):

$$F_e = \frac{4F_1}{3} \tag{3}$$

$$= \frac{4 \times 483}{3} = 644 \text{ N}$$

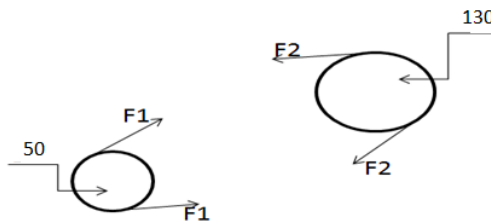


Figure 2: Tension force on transmission belt

2.3.1.6 Design of Shaft

Shaft designs prioritize strength and rigidity under various operating conditions. The diameter of the shaft is critical and is determined using the maximum shear stress theory due to the material's ductility. According to Khurmi and Gupta, (2006), the shaft diameter is derived from equation 4:

$$d^3 = \frac{16}{\pi\tau} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{4}$$

Here, torsional shear stress (τ) for mild steel without keyway is 55 MN/m², and the factors for combined shock and fatigue factor for bending moment (K_b) and combined shock and fatigue factor for torsional moment (K_t) are 1.5 and 1.0, respectively.

2.3.1.7 Calculation of Torque on the Shaft

The torque (T) is given by equation (5):

$$T = \frac{P \times 1000 \times 60}{2\pi N} \tag{5}$$

Where P = 1.81 kW and N = 550 rpm, leading to:

$$T = \frac{1.81 \times 1000 \times 60}{2 \times 3.142 \times 550} = 31.42 \text{ Nm}$$

2.3.1.8 Calculation of Weights and End Reactions on the Shaft (Bhandari, 2010)

For the appropriate shaft diameter selection, consider:

- (a) Weight of the Pulley (cast iron) with a density of 7200kg/m^3 , and diameter of 170mm, producing a mass of 2 kg, is given by:

$$W_p = 2 \text{ kg} \times 9.81 = 19.62 \text{ N}$$

- (b) Tension from Thresher Belt is given by (Equation. 6):

$$F_c = \frac{T}{2r_c} \quad (6)$$

$$= \frac{31.4}{2 \times 0.035} = 448.6 \text{ N}$$

- (c) Weight of Cylinder Drum for a hollow steel material with a density of 7850kg/m^3 , a pipe length, radius and thickness of 0.4m, 70mm and 3mm, respectively, is given by:

$$W = \rho v g = 40.65 \text{ N}$$

- (d) Weight of Cowpea spread on the canvas is given by:

$$W_{\text{cowpea}} = 2.55 \text{ N}$$

The total weight acting on the shaft is the sum of these forces.

2.3.1.9 Calculation of Shear Force and Bending Moment Vertically

In this design calculation, determining the loads and forces acting on load-carrying members, such as the shaft, is crucial. The shaft with the most members and load was selected, and the forces acting on it were resolved. The pulley experiences a resultant V-belt tension at a 41° angle, producing a vertical force of 422.5N and a horizontal force of 486.03N. Similarly, the thresher belt tension, acting at a 3° angle, has vertical and horizontal components of 23.5N and 447.9N, respectively. The free body diagram, shear force, and bending moment diagram of the shaft are illustrated in Figure 3.

The vertical forces acting on the shaft help determine the design. The free body diagram reveals:

- (a) Vertical Component of Pulley Tension is 422.5 N
 (b) Thresher Belt Tension Components at vertical and horizontal are 23.5 N and 447.9 N, respectively.

Vertical Shear Force Calculation

Using the equilibrium of forces showed that, $RBV + RDV = 508.82 \text{ N}$

While taking moments around point D leads to: $RBV = 523.52 \text{ N}$

Thus, $RDV = -14.7 \text{ N}$

Bending Moment Calculation

- Moment at Point A: $MAV = 0$
- Moment at Point B: $MBV = 442.12 \times 0.05 = 22.1 \text{ Nm}$
- Moment at Point C: $MCV = 523.52 \times 0.23 - 442.12 \times 0.28 = -3.39 \text{ Nm}$

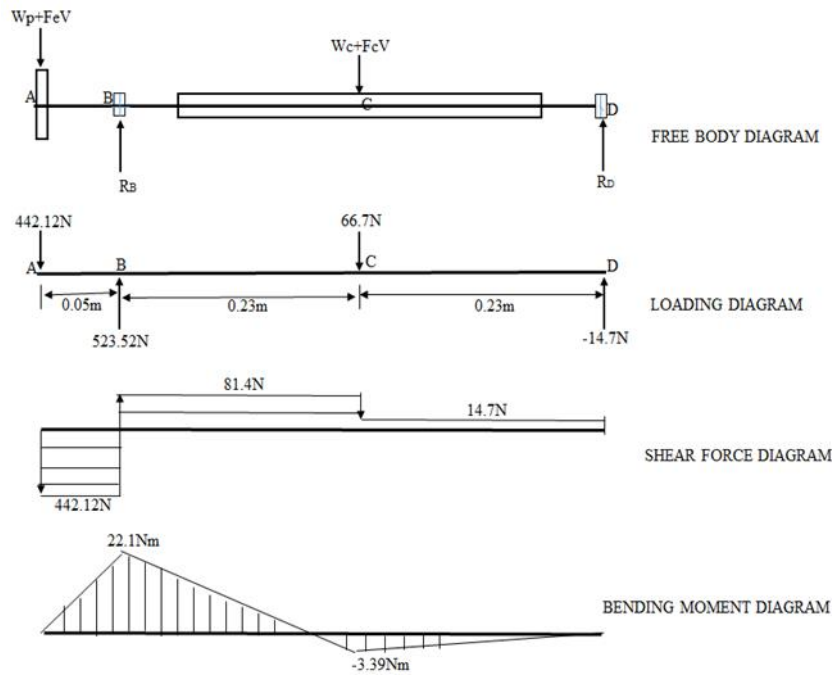


Figure 3: Shear force and bending moment diagram for the vertical component forces

In the horizontal shear force and bending moment calculation, the sum of the upward forces ($R_{BH} + R_{DH}$) equals the sum of the downward forces, giving a total of 934.03N. By taking moments about point D, the reaction force at point B (R_{BH}) is calculated to be 762.87N, and inserting this into the initial equation gives the reaction force at point D (R_{DH}) as 171.16N.

For the horizontal bending moment, the moment at point A, B, C, and D, are 0, 24.3, 39.37, and 0 Nm respectively. The resultant bending moments are calculated as 32.85Nm and 39.52 Nm at point B and point C respectively. These values combine the vertical and horizontal bending moments, as shown in the shear force and bending moment diagrams in Figure 4.

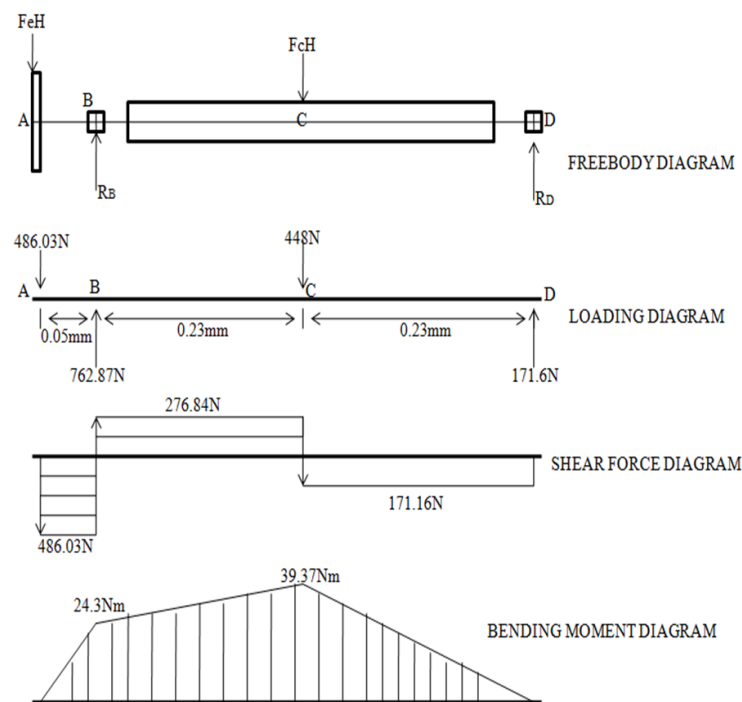


Figure 4: Shear force and bending moment diagram for the horizontal component forces

2.3.1.10 Calculation of Shaft Diameter

The shaft diameter is determined by rearranging the equation for bending and torsional moments, using the equation (7) from Shigley and Mischke, (2008):

$$d^3 = \frac{16}{\pi\tau} \times 67.1 \quad 7$$

The diameter is calculated to be approximately 20 mm.

2.3.1.11 Calculation of Bending and Shear Stress on the Shaft

Using equations 8 and 9 for bending stress and shear stress, respectively (Khurmi and Gupta, 2006):

$$\delta_b = \frac{32M}{\pi d^3} \quad 8$$

And,

$$\delta_{sh} = \frac{16T}{\pi d^3} \quad 9$$

With $M = 39.52 \text{ Nm}$ and $T = 31.4 \text{ Nm}$, the stresses are calculated, and a factor of safety of 3.0 is applied as per design requirements.

2.3.1.12 Bearing Selection

Radial or flat bearings are selected for durability and economic reasons. The design life (L_d) for agricultural machinery is estimated as shown in equation (10) (Khurmi and Gupta, 2006):

$$L_d = L_{10}(h) \cdot (N \text{ rpm}) \cdot 60 \quad 10$$

With a specific design life of 3000–6000 hours and a rotational speed of 550 rpm, calculations yield:

$$L_d = 9.9 \times 10^7 \text{ rev}$$

The dynamic load rating (C_r) and bearing life (L_B) are then computed as 2683.12N and 4294.54h, respectively.

2.3.1.13 Fan Design

The fan's outlet velocity and flow rate are established for effective separation of cowpea from chaff. The calculations include impeller dimensions and power requirements to drive the fan, with torque calculated for the fan drive. The fan's outlet velocity is set at $V_3 = 10 \text{ m/s}$ with a flow rate of $Q = 1.1 \text{ m}^3/\text{s}$ (Allen and Watts, 1998). The power required for the fan is expressed in equation (11) (Osborne, 1997; Dixon and Hall, 2014):

$$P = \frac{Q \times P_s}{\epsilon} \quad 11$$

$$= \frac{1.1 \times 500}{0.75} = 0.73 \text{ kW}$$

Calculating the torque on the fan drive yields $T = 5.3 \text{ Nm}$.

2.3.1.14 Motor Power

The motor power needed is derived from the total power required for threshing and fan operation. A standard motor with sufficient capacity is selected based on efficiency. Minimum motor power required is given by equation 12 (Khurmi, & Gupta, 2005):

$$P_{min} = \frac{P_p}{n} \quad 12$$

where $P_p = 1.81 + 0.73 = 2.54$ kW and efficiency $n = 0.8$, leading to a requirement of 3.18 kW. A 3.7 kW (5 HP) gasoline engine is selected as the prime mover.

2.3.1.15 Design Calculation for Tray

The tray's dimensions and volume are calculated to ensure it effectively holds the cowpea pods, using the formula in equation (13) (Larson *et al.*, 2009):

$$\text{Volume} = \frac{1}{2}(A + B) \times H \times L \quad 13$$

Resulting in a capacity to carry approximately 3.72kg of cowpea pods.

The tray, which holds and guides the plant material, has a volume of 0.012 m³, capable of holding 3.72 kg of cowpea pods based on the pod density of 310.2 kg/m³.

2.3.2 Description and operation of the thresher

The thresher is designed to function as a unit. The principal units are the feeding unit, the threshing unit, the blower unit, the unloading unit, the power transmission unit, and the supporting frame. The feeding unit consists basically of a slanted tray to keep and release the pods as will be required by the threshing unit. The threshing unit is a conveyor arrangement of two separate canvas belts, one lying above another. Both belts run in same direction but at different speeds, the lower belt driving the unit and running a higher speed so as to dictate the direction of travel of the crop. The blower unit is a three forward curved blades attached to a shaft, enclosed in a blower housing. The sides of the blower carry a circular opening to allow air in. The number of blades ensures a steady delivery of air. The unloading unit has two openings. One opening is the chaff outlet, to connect the air velocity from the blower outlet and exit the chaff from the thresher, and the other is an inclined chute at 35° to gently slide the grain into a collecting trough. The power transmission unit consists of the power source (a gasoline motor), V-belts, pulleys, shafts and bearings. The thresher works on the friction rubbing principle. The gasoline engine motor is the power source for rotating the canvas thresher belts. Cowpea is delivered at the feeding unit into the threshing unit. Both travelling belts are in same direction of travel; the lower part of the top belt making contact with the crop at a reverse direction of travel to the top part of the lower belt. The lower belt travels at a higher speed than the top belt so as to allow the crop move from the feed in end of the belt to the exit end. The contact between the top and the bottom belt on the crop creates the threshing by frictional rub and delivering it to the exit end. At the exit end, the grain and chaff fall off and is cleaned by the blower. Grains fall by gravity and the lighter chaff is driven by the forced air (see Figures 5, 6 and 7).

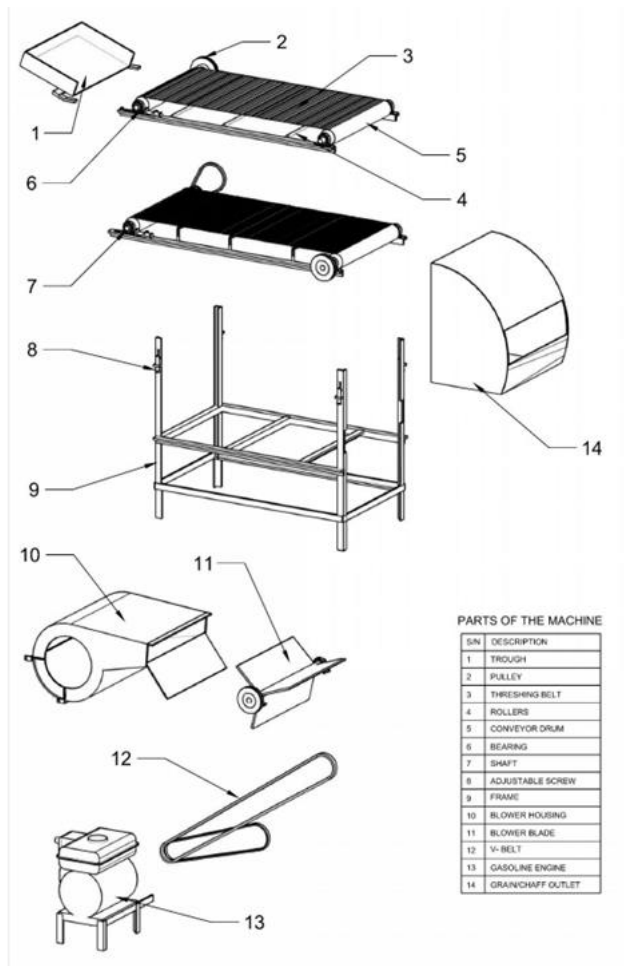


Figure 5: Parts of the Thresher

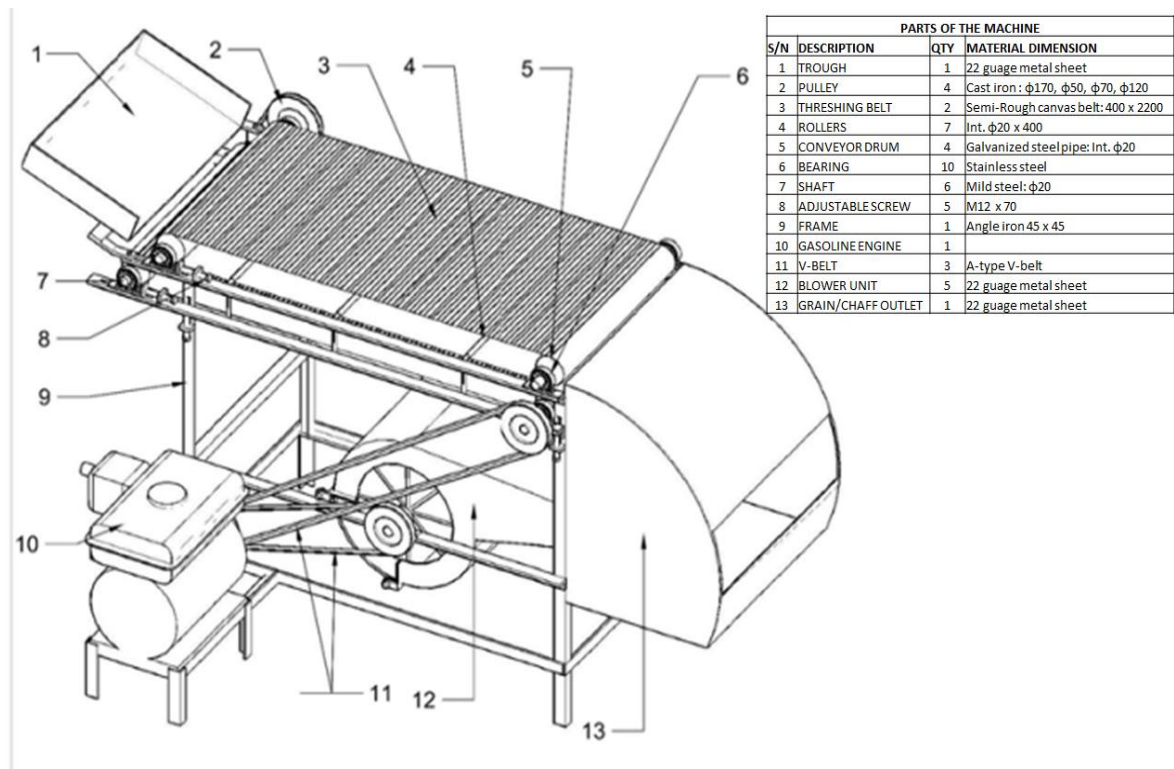


Figure 6: Isometric projection of the thresher

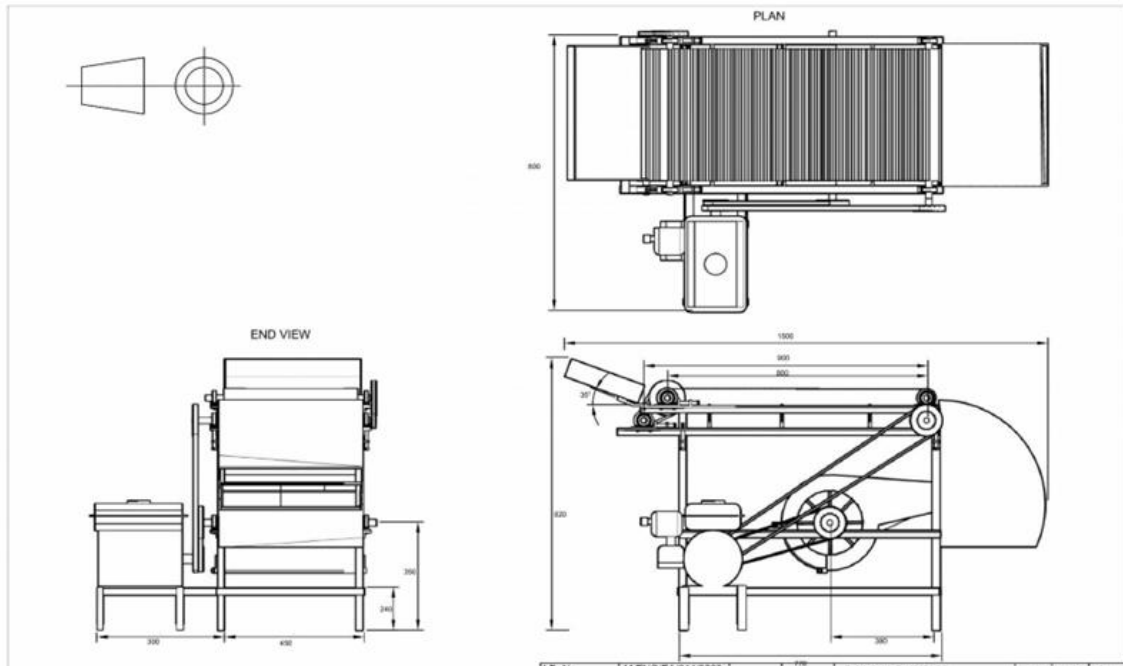


Figure 7: Orthographic projection of the thresher

3. Design Results

The developed canvas belt cowpea thresher is displayed in plate I and the results of the calculations are presented in Tables 1 and 2. The Table 1 is the Table of the principal dimensions of the thresher. It states the overall dimensions of the machine and its volume. The table also gave details of the feeding trough. These values were arrived at after all the designed values were filled in. The trough's inclination angle was chosen knowing from preliminary investigations that cowpea pod has frictional angle of 44° . The Table also contains the principal parameters of the threshing area. It specifies the working mechanism in the threshing area. The drums are specified, so also the thresher belt, its capacity and the power required to drive the unit. Table 2 involves the principal power transmission indices of the thresher. The manipulations of machine parts to achieve the designers desire is seen in the choice of pulleys and pulley sizes, belts, shaft diameter, bearings and the blower parameters. Some were picked from standard tables while others were calculated from design formulae.



Plate I: The constructed isometric view of the canvas belt cowpea thresher

Table 1: Principal Dimensions of the Thresher

Machine dimensions	Value
Inclination angle of tray/trough	45 °
Length of tray/trough	310mm
Average width of tray/trough	580mm
Volume of tray/trough	0.01m ³
Overall machine width	800mm
Overall machine height	820mm
Overall machine length	1500mm
Overall machine volume	0.984m ³
Thresher parameters	
Drum diameter	70mm
Drum length	400mm
Drum speed	550rpm
Thresher belt length1	1100mm
Thresher belt length2	840mm
Threshing belt width	400mm
Belt capacity	6.4kg/s
Power required to drive thresher belt	1.81kW

Table 2: Power Parameters of the Thresher

Parameters of Power transmission systems	Value
Pulley diameter d ₁	50mm
Pulley diameter d ₂	130mm
Pulley diameter d ₃	70mm
Pulley diameter d ₄	170mm
Pulley 1 & 2 speed ratio	2.6
Pulley 3 & 4 speed ratio	2.4
Belt type	V-type
Belt speed	10m/s
Belt cross sectional area	31mm ²
Belt mass per meter run	0.105kg
Shaft diameter	20mm
Bearing type	radial ball bearing (6304)
Bearing inner diameter	20mm
Bearing outer diameter	52mm
Bearing width	15mm
Blower parameters	
Number of blades	3
Blade width	150mm
Blower casing diameter	340mm
Power required to drive fan	0.73kW
Torque on fan drive	5.3Nm
Motor Power	3.18kW

3.1 Cost of Production and Limitations

The cost of manufacturing the canvas belt cowpea thresher was analyzed and totaled ₦253,000. Key materials included galvanized pipes, mild steel rods, and angle iron costing ₦37,300; sheet metal, canvas sheets, and radial bearings at ₦48,200; and bolts, pulleys, cutter blades, and a V-belt contributing ₦33,300. The largest expenditure was a 5Hp petrol engine at ₦65,000, while labor costs accounted for ₦55,000. Miscellaneous components such as welding electrodes were also included to ensure all necessary resources were covered. The study faced several limitations, notably the lack of a factory-made canvas belt, leading to slippage issues due to non-uniformity despite adjustments. Additionally, challenges in sourcing suitable pulleys for the designed shaft further impeded the research process.

4. Conclusion

The design and fabrication of the canvas belt thresher demonstrated a successful reduction in grain damage and an increase in threshing efficiency, making it a viable solution for small-scale cowpea farmers. With locally sourced materials and simple fabrication techniques, the thresher is both cost-effective and easy to maintain. The machine's performance, driven by a gasoline engine, meets the necessary requirements for cowpea threshing, providing a practical alternative to more complex and expensive systems. This innovation is expected to positively impact cowpea production by reducing labor and operational time, thus supporting the agricultural productivity of small-scale farmers.

References

- Allen, CAW and Watts, KC. 1998. Design of a Belt Thresher for Cowpea Beans. *Agricultural Mechanization in Asia, Africa and Latin America (AMA)*. 29(3): 42-46.
- Bhandari, VB. 2010. *Design of Machine Elements* (3rd ed.). McGraw-Hill Education.
- Bureau of Indian Standards. 1985. IS 6284: Test code for threshing machines. Retrieved from law.resource.org.
- Chen, L., Zhang, L., Li, L., and Zhang, L. 2025. Design and experiment of a low-damage threshing drum for corn with stepless taper adjustment. *Agriculture*, 15(1), 4.
- Clark, G. 2007. *A Farewell to Alms: A Brief Economic History of the World*. Princeton University press. USA. 286.
- Daniyan, IA. Adeolu, AO. and Dada, OM. 2014. Design of a Material Handling Equipment: Belt Conveyor System for Crushed Limestone using 3 Roll Idlers. *Journal of Advancement in Engineering and Technology*, 1(1): 2-6.
- Dixon, SL. and Hall, C. A. 2014. *Fluid Mechanics and Thermodynamics of Turbomachinery* (7th ed.). Butterworth-Heinemann.
- El-Shal, MS., El-Ashry, AS., El-Shal, AM. and Fakhrany, WB. 2020. Development of a rubbing thresher for some seed crops. *Misr Journal of Agricultural Engineering*, 31(1), 133-154.
- Fawohunre AJ. and Olajide OG. 2020. Development and performance of a motorized cowpea threshing machine for small scale farmers in Nigeria. *Global Journal of Engineering and Technology Advances*, 05(01), 001–007.
- Fernando, SD. and Hanna, MA. 2005. Design and development of a threshing chamber and pneumatic conveying and cleaning units for soybean harvesting. *Transactions of the ASAE*, 48(5), 1681-1688.
- Fernando, S., Hanna, MA. and Mesquita, C. 2004. Soybean threshing mechanism development and testing. *Transactions of the ASAE*, 47(3), 599-605.
- Gelaw, GK. 2020. Theoretical and experimental investigation of threshing mechanism for tef (*Eragrostis tef* (Zucc.) Trotter) on the basis of its engineering (physical and mechanical) properties (Doctoral dissertation, Addis Ababa University). Addis Ababa Institute of Technology (AAiT).
- Istifanus, AB., Abang, M., Okechukwu, C. and Oloyede, TO. 2022. Design modification, development and performance evaluation of a cereal crop thresher. *American Journal of Engineering Research (AJER)*, 11(3), 140-147.
- Khurmi, RS. and Gupta, JK. 2005. *A Textbook of Machine Design*. S. Chand.
- Khurmi, RS. and Gupta, JK. 2006. *Theory of Machines*. Eurasia Publishing House. New Delhi., 262-263.

- Kutte, MT. 2001. Re-activation and Performance Evaluation of the Threshing of Rice. M.Eng. Thesis. Department of Agricultural Engineering. University of Maiduguri.
- Larson, R., Boswell, L., Kanold, TD. and Stiff, L. 2009. Geometry. Holt McDougal.
- Maunde, FA. 2011. Performance Evaluation of Manual Cowpea Thresher. African Journal of Agricultural Research. 6(30):6412-6415.
- Ojomo AO, Ale MO, and Olajide, OG. 2010. Development and Performance Evaluation of a Cowpea Harvester. Journal of Engineering and Applied Sciences. 5(10), pp 5-10.
- Osborne, WC. 1997. Fans (Int'l series on heating, ventilation and refrigeration). Pergamon press. England. 1:122-139.
- Shigley, JE. and Mischke, CR. 2008. Mechanical Engineering Design (8th ed.). McGraw-Hill.
- Sousa, CC., Damasceno-Silva, KJ., Bastos, EA., and Rocha, M.M. 2015. Selection of cowpea progenies with enhanced draught-tolerance traits using principal component analysis. Genetic and molecular research. 14(4): 15981-15987.