Research Article

International Journal of Advanced Technology and Engineering Exploration, Vol 12(122)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2024.111101148

Design, fabrication, and performance evaluation of a soybean threshing machine

Frederick Abangba Akendola*, Clement Adekunle Komolafe, Abdulai Ayirebi Ankrah and Obed Ofori Yemoh
Department of Mechanical Engineering, Faculty of Engineering, University of Mines and Technology, Tarkwa, Ghana

Received: 30-June-2024; Revised: 12-January-2025; Accepted: 16-January-2025

Abstract
Soybean (Glycine max) is a staple crop with significant nutritional value and serves as a key industrial raw material for animal feed producers. However, in Ghana, soybean production is predominantly carried out manually. The objectives of this study are to: (1) design a soybean thresher using engineering design principles and theories, (2) fabricate the machine utilizing appropriate engineering technologies, and (3) evaluate its performance using design of experiment (DOE) methodologies. The study was done by using computer-aided design (CAD), and dynamics (kinematics) of machinery in the design, machining, sheet metal forming and fastening (welding and the use of bolts and nuts), whereas the DOE technique was used for evaluating the machine's performance. The outcome of the study presents a mechanical soybean thresher, which is ergonomically friendly. The performance evaluation of the machine revealed that the thresher achieved a throughput ranging from 81.2 to 96.4 kg/h and an efficiency of 74.62% to 93.67%, with minimal grain damage proportions between 2% and 4.7%. A strong positive correlation coefficient of 0.85 was observed between operating speed and efficiency, and 0.9 between operating speed and capacity. The study provides predictive models to support precise machine design decisions and offers guidance for future machine designs, with a high coefficient of determination ranging from 0.7219 to 0.8041. Additionally, boxplot analysis indicates a median grain damage proportion of 2.7% with minimal variability, which validates the machine's reliability under controlled operating speed conditions. These findings highlight the machine's operational stability, user-friendliness and minimal fatigue impact, ensuring high-quality soybean processing. Therefore, an efficient, ergonomically friendly, locally developed soybean threshing machine was designed, enabling reliable predictions and decisions within optimal operating conditions.

Keywords
Soybean thresher, Performance evaluation, Engineering design, Design of experiment, Ergonomic design, Predictive modelling, Machine efficiency.

1.Introduction
Soybean (Glycine max) is a critical agricultural product, known for its high nutritional value and versatile characteristics as a raw material for industry [1, 2]. This staple crop contributes significantly to global food security and the economy of agriculture [3]. In Ghana, soybean cultivation serves both the local and export consumption markets. It is a good source of protein in the diet and remains a primary ingredient for animal feed production. Despite its significance, soybean production in Ghana is being done manually, especially during the threshing of the harvested crop.

*Author for correspondence

The manual method of threshing soybeans, which involves separating the grains from pods, is laborious and time-consuming.

This approach not only hinders productivity but also exposes the grains to risks of damage and contamination, quality reduction, and market value loss. Efforts to mechanise the threshing process provide a viable solution to these problems, offering potential enhancements in efficiency, grain quality, and general productivity [4].

Previous studies have acknowledged the challenges associated with manual soybean threshing, mostly in developing countries such as Ghana. Manual threshing is usually inefficient, leading to postharvest losses that cannot be ignored [5, 6]. A study [7] established that manual threshing can result in at most 30% grain loss due to mishandling and contamination. Conversely, the rigorous physical exertion required for manual threshing poses health risks to farmers, especially in rural communities where advanced mechanisation is unaffordable and inaccessible [6]. Existing mechanised solutions to these challenges often fail to address specific indigenous needs in Ghana, although effective in some areas. Imported threshing machines are expensive and very challenging to maintain due to the lack of spare parts and technical expertise considering their complexity [8]. Additionally, these machines may not be designed to thresh and adapt to the specific features of locally grown soybean varieties, resulting in suboptimal performance [9].

The main objective of this study is to develop a soybean thresher for peasant farmers in Ghana. The specific objectives include the following: To design an effective soybean threshing machine using standard methods. To fabricate the machine using locally sourced materials. To evaluate the machine's performance.

This study is motivated to improve the productivity and quality of soybean production in Ghana. This motivation is leveraged against developing a locally designed and fabricated soybean threshing machine, that aims to provide a cost-effective and efficient solution exclusive to the specific needs of Ghanaian farmers. This effort is expected to improve grain quality, reduce post-harvest losses, and alleviate the physical burden on farmers, thus contributing to the general sustainability of soybean production.

Earlier research [10, 11] did not establish how performance metrics such as capacity, efficiency, and grain damage relate to one another and the operating parameters such as speed. This study fills this gap by demonstrating that the capacity and efficiency of the soybean thresher are functions of the operating speed. Also, past studies [12] although evaluated thresher performance, failed to thoroughly analyse how speed affects grain damage or provide detailed statistical analysis. This research identifies an optimal operating speed range that minimises grain damage, which is critical for maintaining the quality of the harvested soybeans. Furthermore, existing literature [13] reported throughput and efficiency values but failed to relate them to the machine parameters in the form of predictive models. This study provides exclusive predictive models that provide a precise framework for enhancing thresher performance. Not only that but also, previous research [14] failed to consistently assess performance across a range of operating conditions or provide clear, controlled tests for grain damage and efficiency. This study addresses this by analysing performance across a range of operating speeds in controlled conditions and establishing specific findings regarding the optimal speed for minimal grain damage. Finally, the literature [15] lacked a detailed approach to how the operational parameters (like speed) can influence machine performance whilst quantitative relationships for optimising these parameters are also lacking. This research provides a predictive model for machine capacity and efficiency, which can be used to make informed design decisions based on the operational speed. The development of these models is new and significantly contributes to the optimisation of soybean threshers.

The work is organised in the following order: Section 1 introduces the study. Section 2 reviews relevant literature on methods of soybean threshing and existing mechanisation technology. Section 3 outlines the thresher design and fabrication methodology. Section 4 presents the study's results. Section 5 discusses the findings, emphasizing the implications for future research and development. Section 6 concludes the study and makes recommendations for further work.

2.Literature review

Soybean (Glycine max) is a crucial crop globally, serving as a source of protein, medicine, fuel, enzymes, and oil [16, 17]. As the demand for soy products surges, there is also an increasing need for cost-effective and efficient agricultural machinery to streamline the postharvest processing phase, especially threshing. One critical piece of equipment in soybean postharvest processing activities is the thresher, a machine which separates soybeans from their pods. Threshing involves separating the beans from the pods [18]. Soybeans are harvested and threshed in advanced countries using more efficient machines, whereas it is done manually or by using simple tools in developing countries like Ghana [19]. In the initial stages of agricultural mechanisation, soybean threshers were modifications of existing grain threshing tools or devices. The initial designs did not consider the physical and mechanical properties of crops and were, hence, limited in performance due to the distinct soybean geometric characteristics. As presented by [14], these designs

produced suboptimal overall output and brought about increasing levels of manual soybean threshing.
Understanding the relationship between soybean characteristics and the operating mechanisms of threshing machinery facilitates the gradual improvement of soybean threshers. Nag and Gite [20] reported the significance of crop-specific adaptations in agricultural machinery design, considering pod shape, resilience, and size. However, thresher designs are expected to account for the influence of features that reduce damage to soybeans during threshing, considering the economic effects of preserving bean quality [21].

Many threshing principles and mechanisms have been explored and applied in sophisticated combines for crop threshers. They include tangential flow, rotary systems, and axial flow [22–24]. Axial flow systems use rotating cylinders to thresh while tangential flow combines radial and axial motion of the input substance. The rotary mechanism adopts beaters and rotating blades to achieve the threshing process. Each mechanism has various strengths and limitations. They also significantly influence efficiency, energy consumption, and overall performance output [25, 26]. Rotary and tangential flow in threshing systems at the onset of mechanisations for crops like rice, cowpea, peanuts, etc. encountered significant challenges in properly threshing soybeans thus, bringing about low efficiency and higher energy consumption [27]. Subsequently, Guo et al. [28] developed and explored axial flow mechanisms in which the limitations and advantages of crops like rice, cowpeas, peanuts, etc. were detailed. Despite the availability of these alternatives, the desire for an efficient threshing machine for soybeans discovered the axial flow mechanism as the most appropriate due to its immense advantage of allowing a longer time for the pods to travel along the threshing mechanism for complete and efficient threshing to be achieved. The significance of flexibility and adjustability in engineering machinery design is also critical in the design of soybean threshers due to changing environments and crop conditions. The merits of adjustable parameters, such as concave clearance, rotor speed, and sieve openings based on the geometric mean diameter of the beans, were discussed by [9]. These properties allow farmers to assess the thresher's performance under varying crop conditions and using different soybean varieties, underscoring optimal efficiency under varying environmental factors [29].

The advancement of engineering materials and fabrication techniques since the Industrial Revolution has helped address issues related to weight, rotor speed, vibration, and cost by incorporating lightweight materials such as steel alloys [30, 31]. “The integration of advanced manufacturing processes, including computer numerical control (CNC) machining and 3-dimensional (3D) printing, has improved precision and reliability”, although it is not prevalent in the Ghanaian manufacturing landscape [32]. Despite the progress made in soybean thresher design and fabrication, challenges persist partly due to economic reasons.

Researchers, including [33, 34], have developed engine-operated soybean threshers to reduce the drudgery associated with manual soybean threshing by applying the principles of engineering design, construction, and evaluation. Despite the ever-evolving attempts to mechanise soybean threshing in Africa, it is still gaining traction in rural areas of Ghana such as Nyankpala, Bawku, Yendi, Manga, Wa East, etc. where [35] identified these cities as the epicentres of soybean production in Ghana.

A cost-effective soybean thresher, emphasizing simplicity and ergonomics, was designed and fabricated by [36] using locally sourced materials to minimize production costs. They obtained a machine threshing efficiency of 85% and a capacity of 150 kg/h. Although the machine had low production and operation costs, it has the advantage of easy maintenance, and suitability for small-scale farmers but lower efficiency and limited capacity in contrast with industrial-scale machines.

Conversely, testing a pedal-operated soybean thresher developed by [37, 38] to address the challenge of lack of power supply in threshing soybeans in rural areas quantified its performance using its threshing efficiency and output capacity. The equipment was determined to be efficient based on their throughput of 100 kg/h and 150 kg/h respectively. The equipment operated without electricity, making it useful in remote off-grid areas. Nonetheless, the efficiency was found to be low relative to motorised threshers and at the same time proved to be labour intensive.

Studies conducted by Harerimana et al. [39] employed the design of a semi-automated soybean thresher, which adopted a drum with pegs and a concave sieve. The performance of the machine was evaluated under varying moisture content. The obtained machine's threshing efficiency varied from 80-92% depending on moisture content. The highest efficiency was obtained at 12% moisture content. It was reported that machine efficiency significantly decreases with higher moisture content.

According to Yogaraj et al. [40], soybean threshers have threshing efficiency and capacity of 88% and 120 kg/h respectively. This represents the findings of a study [40] conducted by designing a portable soybean thresher suitable for smallholder farmers in Ghana. The machine used a rotary drum with a concave and sieve system resulting in a portable and ergonomic soybean thresher that is suitable for rural settings but was limited in capacity and durability when used for an extended period.

An electrically powered soybean thresher was fabricated by Lee et al. [41]. This soybean thresher was assessed and evaluated under varying feed rates and speeds, where an optimal performance was achieved at a speed of 800 rpm, a feed rate of 200 kg/h, and an optimum efficiency of 90%. Whereas it depended solely on electrical power for its operation, which may be undesirable, it has a high capacity and efficiency whilst being suitable for medium-scale production under the same circumstances.

A solar-powered soybean thresher was designed and fabricated by Harerimana [42] to address energy sustainability challenges. Testing the machine’s performance under different solar conditions revealed a threshing efficiency of 85% under optimum sunshine and a 140 kg/h capacity. The thresher employed renewable energy sources, reduced operation costs, and provided numerous environmental benefits and no ecological hazards were realised. However, one major limitation is that its performance is highly dependent on weather conditions, making it record low efficiency equipment on cloudy days since it has no alternative power source.

The advent of advanced technology is also gaining traction in agriculture. Therefore, [43] introduced an artificial intelligence (AI) based control system for predicting the performance of flexible threshers. Ma et al. [43] concluded that backpropagation neural networks could predict the threshing performance of the flexible threshing device with an acceptable degree of accuracy (R = 0.980, $RMSE$ = 0.138, RMSE = 0.138, MAE = 0.153, MAE = 0.153).

Hanna and Quick [44] designed a hybrid soybean thresher that combines mechanical and pneumatic separation mechanisms to improve seed cleaning efficiency. This product obtained an effective threshing and cleaning efficiency of 92% and an output capacity of 180 kg/h. Whereas its efficiency was high in both threshing and cleaning whilst being suitable for medium to large-scale operations, it has a very high-power requirement and is relatively complex.

Chandra et al. [45] reported that during harvesting, the moisture content significantly affects post-harvest losses, including factors that reduce the quantity and quality of agricultural produce. These factors involve pre-harvest sprouting, mechanical damages and susceptibility to diseases during storage.

Again, Mussema et al. [46] developed a location and community-based soybean threshing service model using a mobile thresher. Threshing efficiency was 87% and capacity was 160 kg/h. It was highly accepted in the communities and was found to have increased productivity. It was less expensive to operate as farmers shared the cost. It increased thresher accessibility and promoted community cooperation. It was however not devoid of scheduling conflict as its operation depended on community management.

Studies conducted by Wang et al. [47] involved the design of a soybean thresher with a “rotary drum mechanism”. Rubber-coated rasp bars were used to reduce grain damage. Finite element analysis (FEA) was also used to enhance the speed and geometry of the drum. The fabricated product was assessed to evaluate its efficiency, grain damage proportion and throughput at different moisture content and speeds. This thresher achieved a 95% efficiency, 2.5% grain damage proportion at 12% moisture content and a 300 kg/h throughput. The integration of experimental validation and FEA made the design technique very robust, and one of the key performance metrics (the damage proportion) was significantly minimised due to the use of rubber-coated rasps on the drum. The limitations were that there was a huge decline in the key performance metrics when the moisture content increased by more than 15%.

The design and fabrication of a portable soybean thresher is another study conducted by [45] to address the challenges of smallholder farmers, where the threshing unit had a peg-type drum. The thresher was solely made from locally sourced materials.

Evaluation of the thresher revealed an efficiency of 88-93% and a 200 kg/h throughput. The design and modelling technique employed in this study made it less sophisticated and more affordable. The limitations however were that its lower throughput made it unsuitable for large-scale production, and the peg-type drum increased the damage proportion up to 7% relative to advanced mechanisms.

Another study conducted by Marina et al. [48] involved the integration of an AI approach to enhance the design and operating parameters of a soybean thresher using machine learning algorithms. The optimization obtained a 97% threshing efficiency and a 2% grain damage proportion with adaptive characteristics under varying moisture content. The advantages were that the adoption of the AI approach minimized the rule-of-thumb in the design process and the positive adaptive capabilities enhanced versatility in varying environmental conditions. The difficulty however was that the dependence on machine learning algorithms requires adequate technical expertise and computational resources, which may be a hindrance.

Lal et al. [49] in a study contrasted manual and mechanical threshing of soybeans, where economic viability, threshing time and labour requirements were evaluated. The outcome revealed an 80 and 70% reduction in labour requirement and threshing time respectively. The good thing was that the obvious economic merit of mechanization was demonstrated in relation to labour requirements despite its high initial cost and the need for regular maintenance.

These previous studies demonstrate a substantial advancement in the design, fabrication, and performance evaluation of soybean threshers. The fundamental methodologies ranged from manual to semi-automated and fully automated systems, with each streamlined towards specific farming scales and conditions. Modern designs are observed to generally achieve higher efficiencies (80-95%) and operating capacities (100-200 kg/h). Superior performance is demonstrated by automated and hybrid systems but they come with higher costs and advanced sophistry. Solar- and pedal-operated threshers have lower capacity and efficiency; however, they effectively address energy challenges. The electrically powered machines provide higher performance but are constrained by electricity availability. Modern innovation such as hybrid mechanisms and AI-based controls significantly improves performance but are not found to be feasible for small-scale farmers due to cost implications and sophistication.

Unlike previous studies that adopted different threshing mechanisms, this study employs a screw auger in the design of the drum to allow for easy transport of threshed grains. In northern Ghana where huge volumes of soybeans are produced, most indigenes are subsistence farmers and depend on it for food and income. They employ manual tools like sticks in manually threshing their harvested produce, thus, contaminating the grains and giving it a low value and short storage life. Considering the low standard of living and the economic condition of the inhabitants in the producing areas of the crop in Ghana it is imperative to develop an efficient, yet less expensive soybeans thresher that will resonate well with the people and fall within their purchasing power. This is because the use of the mechanical soybean thresher is an improvement on the manual threshing modes mostly depended upon, yet less sophisticated and less expensive, not only affordable to the local Ghanaian farmer but also eliminating the stress and inconveniences involved in the manual threshing process. Therefore, the objective of this work is to design and fabricate a simple mechanical soybean thresher that is powered by a gasoline engine and has a winnower that will separate the grain from the debris thus, alleviating the drudgery involved in the manual threshing process.

This study is expected to contribute to the effort of Ghana to mechanize the agricultural sector to increase production. The findings are useful to proprietors, technologists, and policymakers in sustaining consistent soybean production in appreciable quantities to at least meet internal consumption demands.

3.Methods

3.1Introduction

This section details how the study was conducted. The study was conducted in three major phases namely: the design, fabrication and evaluation. Each of the phases was executed using a systematic approach grounded in engineering principles and methodologies in line with the flow chart illustrated in *Figure 1*.

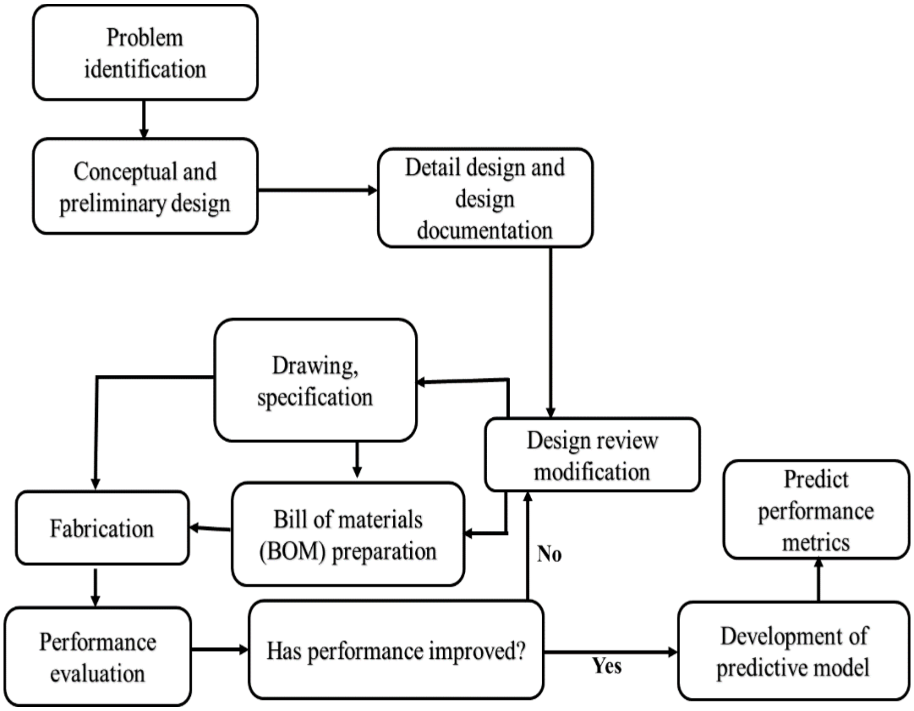

Figure 1 Schematic representation of the research method

3.2Systematic procedure

The design phase comprised preliminary investigation, design considerations, design calculation (the dynamics of machinery) and detailed drawing. The fabrication phase comprised machining, sheet metal forming, and welding and joining, whereas the DOE technique was used for evaluating the machine's performance, where a controlled experimental test was conducted on the thresher using multiple testing approaches to evaluate the influence of operating and machine parameters (drum speed and moisture content) on the critical performance metrics (capacity, grain damage proportion and machine efficiency). The experimental design adopted is the fractional factorial design where a few combinations of the parameters (that is, the drum speed against the critical performance metrics at an optimal moisture content) are tested to reduce the number of experiments.

3.3The design phase

3.3.1Factors considered in the design

To design a machine that ensures optimum overall output, the following criteria were adhered to.

i. Selection of available, less expensive, yet good-quality materials for the construction.
ii. Design against failure by considering the maximum load on the drum and blower shafts under tension, compression, torsion, and bending during the threshing process.
iii. Consideration of crop characteristics such as the moisture content and geometric mean diameter of the soybean grains to allow for efficient design of the concave.
iv. Ergonomic considerations (stability, vibration, and the average height of farmers during the sizing of the machine).
v. Design for failure (All components are bound to fail hence certain elements like shafts, fasteners, etc. were designed to allow for replacement).

3.3.2Components and design calculations

Frame

The frame (*Figure 6*) is the structure on which all other components of the machine rest. To make the machine portable, the frame was designed to be 750 mm long, 914 mm high, and 450 mm wide. It is fabricated in the shape of a rectangular prism using angle bars. They were fastened together using weldments through electric arc welding.

Cylinder

The cylinder is the main threshing mechanism. It was designed to have a length (L_c) of 740 mm. It is a sheet metal of thickness (t_c) 3 mm rolled around the drum shaft and closed at the ends with a metal disc of diameter, d_c = 294 mm to have a diameter of 300 mm. The metal sheet thickness used for the entire construction is 3 mm. The spikes and the screw auger were welded around the drum at a constant pitch (P_s) and extended 50 mm from the surface of the drum. It was held with the drum shaft to the frame by two bearings and driven by the prime mover using a belt and pulley drive. The cylinder is shown in (*Figure 8*) with the concave.

Hopper

The hopper (*Figure 9*) is the inlet for the feed into the thresher. It was designed as a truncated trapezoidal pyramid using sheet metal (mild steel). Its inlet cross-sectional area is 55650 mm^2 and its outlet cross-sectional area, which serves as an inlet to the threshing mechanism is 17940 mm^2. The vertical height is 300 mm and the front side is inclined at an angle of 31° to the vertical. It was designed to have a maximum volume of 11.76 m^3.

Given that the density of mild steel (ρ_s) is 7850 kg/m^3 [50], Mass of Cylinder, M_c and the volume of the solid material in the cylinder is V, the moisture content (M_c) was obtained according to Equation 1.

$$M_c = \rho_s\left(\pi \mathrm{t}_c{}^2 L_c + \pi \frac{d_c{}^2}{2} t_c\right) \quad (1)$$

Screw conveyor (auger) capacity, Q (kg/h) was computed using Equation 2.

$$Q = 15 \times \pi \times D^2 \times S \times N \times \alpha\rho \times C \quad (2)$$

where; D = auger diameter (m), S = auger pitch (m), N= auger speed (750 rpm), α = loading ratio (0.3), ρ = material density (642 kg/m^3), C = inclination correction factor = 1.

The angle of twist of the threshing mechanism, θ (°), which is the angular deformation of the threshing mechanism under torsional load did not exceed the permissible value of 1.2 °/m and was theoretically determined using Equation 3.

$$\theta = \frac{180TL}{\pi GJ} \quad (3)$$

where; T = maximum torque (Nm), L = length of cylinder (m), G = modulus of rigidity (79 GPa for mild steel), J = polar second moment of area of the cylinder (m^4).

The velocity of threshed materials in the threshing chamber, v (m/s) was determined using Equation 4.

$$v = 2\pi \frac{Nr}{60} \quad (4)$$

where; r = radius of threshing cylinder.

Length of threshing cylinder belt, L_{TH}, which is sufficient to prevent slip during operation was calculated according to Equation 5.

$$L_{TH} = 2C + 1.57(D_{TH} + D_E) + \frac{(D_{TH}+D_E)^2}{4C} \quad (5)$$

where; $D_E = 40\ mm$ is the diameter of the pulley on the prime mover, $D_{TH} = 110\ mm$ is the diameter of the pulleys on the threshing cylinder, and $C = 714\ mm$ is the centre distance between the two pulleys.

The angle of wrap, φ (°), which is necessary for computing the tension in the tight and slack side of the belt was computed according to Equation 6.

$$\varphi = 180 \pm 2 \times sin^{-1}\left(\frac{D_{TH}-D_E}{2C}\right) \quad (6)$$

The tension in the tight and slack side of the belt, T_1 and T_2 respectively of the vee belt were determined using Equations 7 and 8.

$$(T_1 - T_2)\omega = P \quad (7)$$

And

$$\frac{T_1}{T_2} = e^{\frac{\mu\varphi}{sin\beta}} \quad (8)$$

where; $\mu =$ co-efficient of friction for vee rubber/leather belt on steel (0.15), $2\beta =$ internal angle of vee belt (40 º), P = input power (W), ω = angular velocity, e = Euler’s number.

Shafts design

This is a rotating machine element that transmits power from the prime mover to the threshing mechanism or the cleaning unit (blower). For rotating machine elements, it was necessary to develop a solid circular shaft, taking into consideration its torsional and bending stresses and assuming that all axial loads on the shaft are negligible. The factors considered in the design of the shaft include the shaft's rigidity to resist torsion and bending, durability and toughness, strength, and wear rate reduction. The diameter (d) of the shaft was computed according to the maximum shear stress theory (MSST) for a solid shaft with negligible axial loading [51] using Equation 9. Given that α_o = Bach’s correction factor = 0.7, FS = factor of safety = 2, R_e = yield stress of mild steel = 250 x 10^6 Nm^{-2}.

$$d \geq \sqrt[3]{\frac{16\alpha_N}{\pi\tau_{all}}\sqrt{M_b{}^2 + (\alpha_o T)^2}} \quad (9)$$

$$\tau_{all} = \frac{0.577R_e}{FS} \quad (10)$$

$$T = \frac{P}{\omega} \quad (11)$$

$$\omega = \frac{2\pi N}{60} \quad (12)$$

where; d = shaft diameter, α_N = stress concentration factor, τ_{all} = allowable shear stress (Nm^{-2}), M_b = maximum bending moment (Nm), T = maximum torque (Nm), N = number of revolutions per minute.

Blower (fan)

The blower consists of a 740 mm long, 10 mm diameter mild steel shaft ($d \geq 8.16\, mm$) with four fan blades at 90° to each other bolted to a bushing and fastened to the shaft. Each blade spans 650 mm and they are replaceable.

The blower design allows for the generation of centrifugal force to blow air during operation. Since the chaff is lighter in weight compared to the grain, the blown air carries away the chaff and allows the grain to accumulate on the incline for onward collection. The blower's large bottom, top, and sides are held to the frame by frame by weldment through arc welding to guide the moving air during the cleaning process, whereas the blower's small side casing welded to the small back casing is fastened to the front component by bolts and nuts.

The rotational speed of the blower, N_B (rpm) was calculated according to Equation 13.

$$N_B = N_{TH} \frac{D_{TH}}{D_F} \quad (13)$$

where; $N_{TH} =$ rotational speed of the threshing cylinder (750 rpm), D_{TH} and D_B are the diameter of the pulleys on the threshing cylinder and blower, carefully chosen as 110 and 240 mm respectively and $N_B = 413\, rpm$.

Length of blower belt, L_B sufficient to drive the fan was computed according to Equation 14.

$$L_B = 2C + 1.57(D_{TH} + D_F) + \frac{(D_{TH}+D_F)^2}{4C} \quad (14)$$

The angle of wrap, φ (°), which is necessary for computing the tension in the tight and slack side of the belt was computed according to Equation 15.

$$\varphi = 180 \pm 2 \times sin^{-1}\left(\frac{D_F - D_{TH}}{2C}\right) \quad (15)$$

The tension in the belt, T_1 and T_2 were determined according to equations 7 and 8.

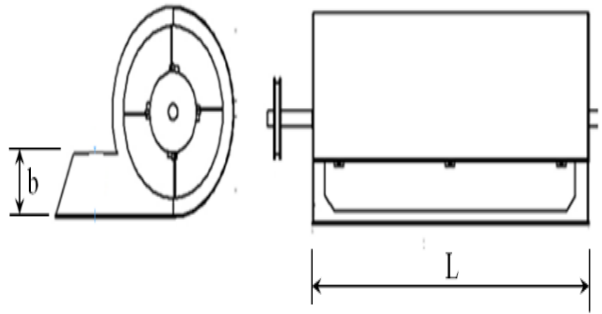

Figure 2 Dimensions of generated wind delivery port

The peripheral speed of air/wind generated by the blower is shown in *Figure 2* at the wind delivery port, v_B (m/s) estimated using Equation 16.

$$v_B = 2\pi \frac{N_B}{60} r_B \quad (16)$$

Volume flow rate of wind-generated, V_{air} (m^3/s) computed using Equation 17.

$$V_{air} = Lbv_B \quad (17)$$

where; $r_B =$ radius of the fan blade from the centroidal axis of the blower shaft (124 mm).
Density of air (ρ_{air}), soybean debris (ρ_{soy}) and water (ρ_{water}) are 1.2, 0.0061, and 1000 kg/m^3, respectively. Debris will float in the air because it is less dense than air.

The pressure generated by air, P_{air} (kPa), which was significant to blow off the debris was computed according to Equation 18 supported by Equation 19.

$$P_{air} = \frac{\rho_{sp} v_B}{2g} \quad (18)$$

$$\rho_{sp} = \frac{\rho_{air}}{\rho_{water}} \quad (19)$$

The total power requirement of the blower sufficient to generate the required pressure was determined using Equation 22 and supported with Equations 20 and 21.

Blast power, P_b (kW)

$$P_b = \frac{0.735 P_{air} V_{air}}{75} \quad (20)$$

Blower shaft power, P_s

$$P_s = \frac{P_b}{\eta_b} \quad (21)$$

Total Power requirement of the blower, P_t

$$P_t = \frac{P_s}{\eta_t} \quad (22)$$

Torque transmitted by blower shaft, T_b during its operation in separating the debris from the grain was calculated using Equation 23.

$$T_b = \frac{60 P_s}{2\pi N_B} \quad (23)$$

where; $\rho_{sp} =$ specific gravity, g = acceleration due to gravity, $\eta_b =$ blast efficiency = 40% ($40 \leq \eta_b \leq 70$), $\eta_t =$ transmission efficiency = 80% ($80 \leq \eta_t \leq 100$).

Design outcome

Table 1 illustrates the soybean thresher's design specifications, obtained through the design computations using Equations 1 to 23.

Table 1 Design specifications

S. N.	Design parameter	Value
1	Frame dimensions (m)	0.75 × 0.45 × 0.95
2	Hopper inlet cross-section (m^2)	0.056
3	Hopper outlet cross-section (m^2)	0.018
4	Hopper inclination with the vertical (º)	31
5	Threshing cylinder length (m)	0.74
6	Threshing cylinder diameter (m)	0.3
7	Threshing cylinder mass (kg)	3.362
8	Screw auger pitch (m)	0.05
9	Screw auger capacity (kg/h)	22292.545
10	Angle of twist of threshing mechanism (º)	0.004
11	Torque of cylinder shaft (Nm)	7.714
12	Velocity of the threshing chamber (rad/s)	78.54
13	Velocity of threshing chamber (m/s)	11.781
14	Length of threshing cylinder belt (m)	1.67.941
15	Angle of wrap (º)	192.059
16	Tension in the tight side of the belt (N)	3.32
17	Tension in the slack side of the belt (N)	0.896
18	Blower speed (rpm)	413
19	Length of blower belt (m)	2.07
20	Air velocity (rad/s)	43.249
21	Air velocity (m/s)	5.363
22	Volume flow rate of blown air (m^3/s)	0.804
23	Air pressure (Pa)	0.33
24	Blower shaft torque (Nm)	0.042
25	Blast power (W)	2.6
26	Blower shaft power (W)	1.82
27	Power requirement (W)	2.275

3.3.3Machine description and principle of operation

The developed soybean thresher (as shown in *Figures 3, 4* and *5*) comprises five units as presented in *Table 2*, namely: The frame, lower casing, cylinder (drum) and concave, top cover casing, and blower (separation unit) shown in *Figures 6, 7, 8, 9* and *10* respectively. The components are supported by a 750 mm long, 914 mm high, and 450 mm wide frame. The threshing mechanism consisted of a 740 mm long drum made of a rolled metal sheet around a shaft that extends beyond the drum and closes at the end. Around the drum are spikes and screw auger. This novelty enables threshing by stripping the pods off the stalks for threshing and easily transporting the grains in an axial flow during threshing as existing thresher designs have either the peg, loop, hammer mill, rasp, angle bar or spike tooth cylinder type. The prime mover is a 1.3 hp, 1200 rpm gasoline engine. A 0.75 speed reducer was coupled to the transmission system (belt and pulley drive) to step down the speed for the threshing drum. The hopper takes in the feed according to the throughput of the machine and supplies it to the threshing mechanism. The concave supports threshing and allows the threshed materials to move into the separation unit for cleaning. The separation unit, which employs a pneumatic separation mechanism comprises a four-blade fan (blower), held by a bushing around a 15 mm diameter shaft ($d \geq 8.16$ mm) to blow off the debris from threshed grain. The blower shaft is held by two bearings and a pulley coupled to it. The rotational speed of the threshing drum serves as the input speed to the blower.

The structural and kinematic simulations on the design were satisfactorily conducted using FEA and Simulink to enhance the machine's smooth performance before fabrication. The structural analysis of these tests assessed the machine's key components such as the rotating shafts for the drum, fan and frame under expected static and dynamic loads to identify deformations, stress distributions, and factors of safety so that the design could be resilient to operational forces. The dynamic simulation analyzed the motion of moving parts, such as the threshing drum and shafts, to evaluate velocities and potential interference during operation. Results were used to finetune the design, resolve critical stress points, and ensure smooth mechanical motion, thus providing a reliable basis for fabrication. Several mechanical processes are involved in the operating principle of a soybean thresher to achieve the desired final threshing effect. First of all, the dried soybean plants with pods are fed into the machine manually through the hopper. The separation of the bean pods from the rest of the plant is achieved by the rotating effect of the drum. The spikes on the drum then cause an impact on the pods against the drum and the concave to break the pods open. The chaff is thrown out through an exit as the auger transports them from the point of entry to the exit point and the threshed materials proceed through a concave (sieve) for cleaning in the separation mechanism. The cleaned beans that eventually fall on the incline are collected in a container placed under the grain outlet. The various machine elements of the thresher are presented in *Table 3*.

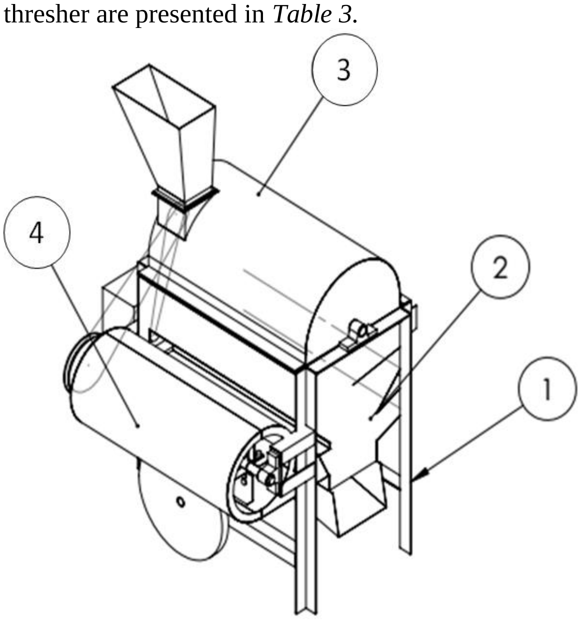

Figure 3 Isometric view of the mechanical soybean thresher

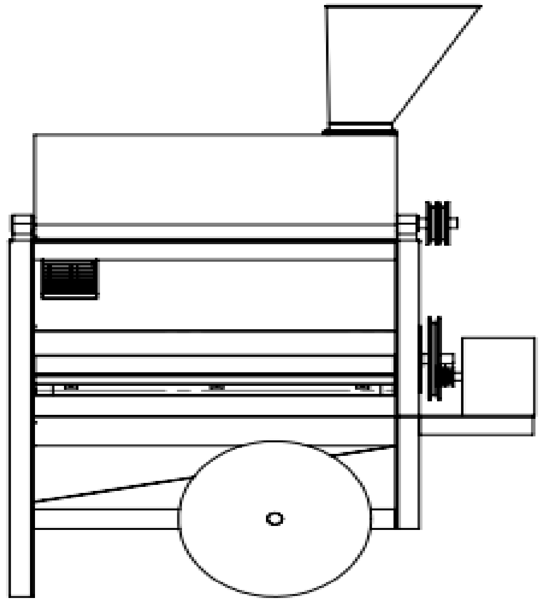

Figure 4 Front view of the mechanical soybean thresher

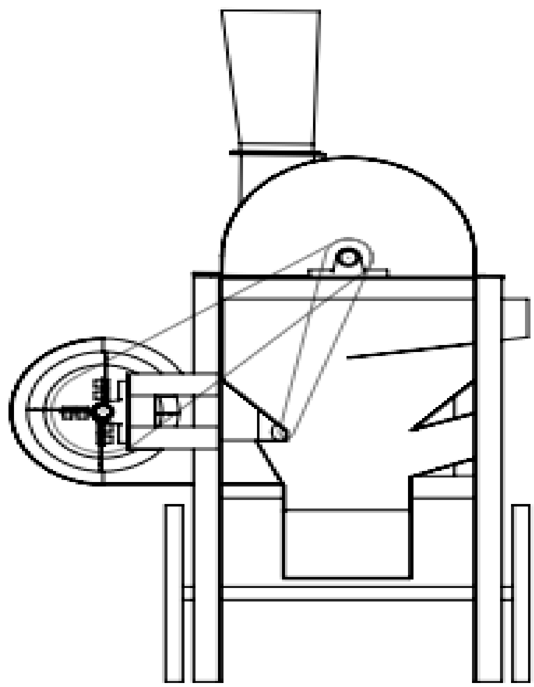

Figure 5 End view of the mechanical soybean thresher

Table 2 Unit of the main thresher assembly

Unit No.	Name of subassembly
1	Frame assembly
2	Lower casing assembly
3	Cylinder and concave
4	The top cover casing assembly
5	Blower assembly

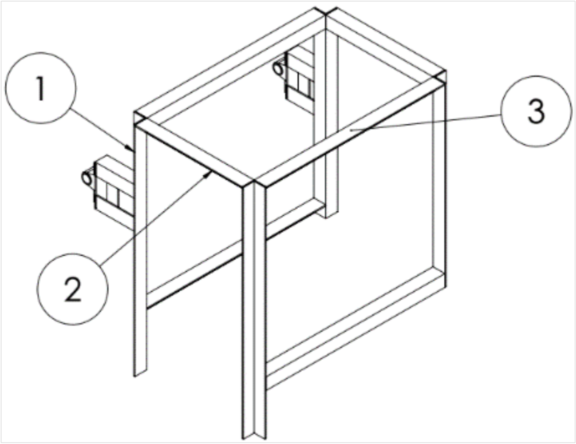

Figure 6 Frame assembly

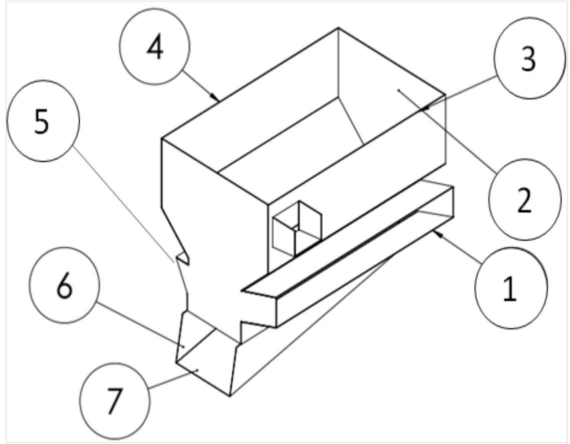

Figure 7 Lower casing assembly

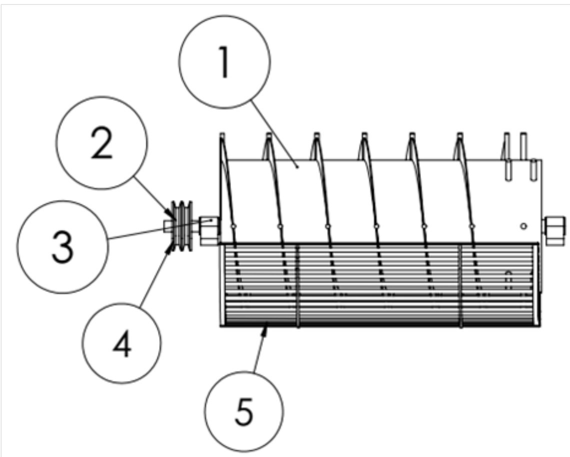

Figure 8 Cylinder and concave

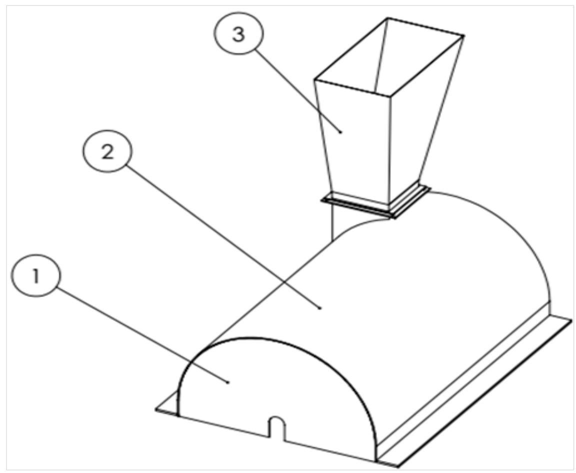

Figure 9 Top cover assembly

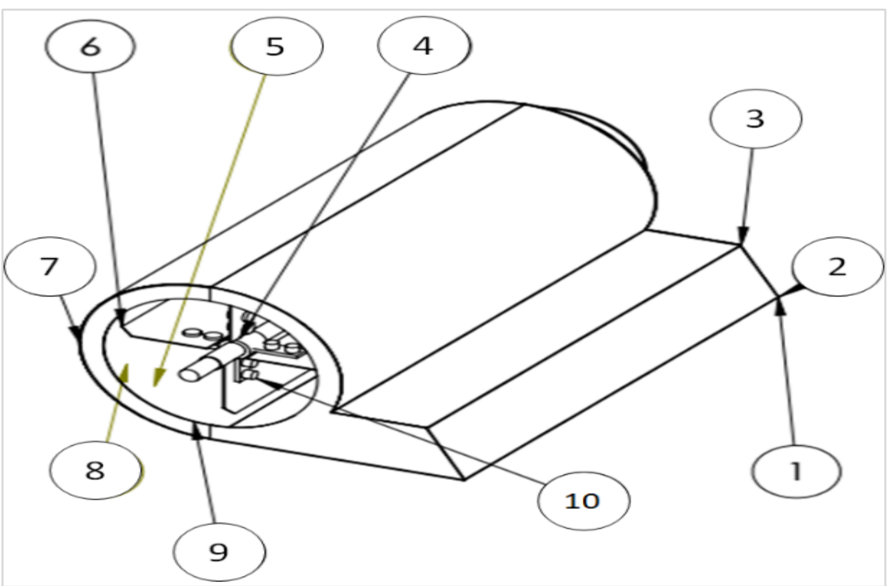

Figure 10 Blower assembly

Table 3 Part list of the mechanical threshing machine

Part No.	Part name	Material	Quantity
	Frame assembly		
1	Vertical bar	Mild steel	4
2	Horizontal bar	Mild steel	2
3	Cross horizontal bar	Mild steel	4
	Lower casing assembly		
1	Front small casing	Mild steel	2
2	Side lower casing	Mild steel	1
3	Front large casing	Mild steel	1
4	Rear large casing	Mild steel	1
5	Rear small casing	Mild steel	1
6	Outlet	-	2
7	Incline	Mild steel	1
	Cylinder and concave		
1	Drum	Mild steel	1
2	Shaft	Mild steel	1
3	Bearing	Bought	2
4	Shaft pulley	Bought	1
5	Concave	Mild steel	2
	The top cover casing assembly		
1	Side cover casing	Mild steel	2
2	Cover metal casing	Mild steel	1
3	hopper	Mild steel	1
	Blower assembly		
1	Large bottom casing	Mild steel	1
2	Large side casing	Mild steel	1
3	Large top casing	Mild steel	2
4	Bushing	Mild steel	2
5	Blower shaft	Mild steel	1
6	Blade	Mild steel	4
7	Small back casing	Mild steel	2
8	Large back casing	Mild steel	1
9	Small side casing		2
10	Screw	Bought	16

3.4Fabrication phase

After the assembly and detail drawing (working drawing) were produced using SolidWorks version 2022, the machine was fabricated according to the working drawing by marking and cutting out (*Figure 11*), welding (*Figure 12*), thread fastening (*Figure 13*), and assembling (*Figure 14* and *Figure 15*).

Figure 11 Marking and cutting out of the soybean thresher components

Figure 12 Welding of the soybean thresher components

Figure 13 Fabricated component (blower/fan) of the mechanical soybean thresher

Figure 14 Fabricated components (threshing and cleaning unit) of the mechanical soybean thresher

3.5Evaluation of machine performance

The complete fabricated machine as illustrated in *Figure 15* was run at no load to ensure that there was stability and adequate clearance for mating parts during rotations. After the satisfactory no-load test, five groups of dry samples at 15% moisture content on a wet basis of soybeans/stalk mixture were prepared in batches (30 kg each). According to [52, 53], threshing wet samples severely crushes the grain and causes massive contamination. The hopper fed a 30 kg sample of soybeans/stalk mixture into the machine. The total mass of material (soybeans/stalk mixture) used for the experiment was 150 kg. Data were collected on threshed, unthreshed, and damaged grain. The experiment was repeated thrice each at a varying rotational speed of the drum from 600 – 900 rpm at an interval of 50 rpm. The parameters for the performance analysis (performance metrics) of the machine were determined using Equations 24 to 28.

$$C = \frac{M_s}{t_s} \quad (24)$$

$$T_p = \frac{M_{th}}{M_t} \quad (25)$$

$$U_p = \frac{M_u}{M_t} \quad (26)$$

$$D_p = \frac{M_d}{M_t} \quad (27)$$

$$\eta_{th} = \frac{T_p}{T_p+U_p+D_p} \times 100 \quad (28)$$

where;

C = the Throughput (kg/h) of thresher, M_s = mass of sample threshed (kg), t_s = time taken to thresh sample (h), T_p = proportion of threshed grain, M_{th} = mass of threshed grain (kg), M_t = total mass of sample (kg), U_p = proportion of unthreshed grain, M_u = mass of unthreshed grain (kg), D_p = proportion of damaged grain, M_d = mass of damaged grain (kg), η_{th} = thresher efficiency.

Figure 15 Photograph of the mechanical soybean thresher

3.6Tools, equipment, and materials used

Table 4 illustrates the tools used in this study, their functions, and materials used in the fabrication of the soybean thresher.

3.7Data analysis

Data collected from the tests were analyzed using the statistical analysis tool packed in Microsoft Excel at a 5% significance level using multiple testing approaches.

Table 4 Tools and equipment used in machine fabrication and their functions

S. N.	Tool/Equipment	Function	Materials
1	CAD tools (SolidWorks)	Production of detail and assembly drawing	Sheet metal (mild steel)
2	Steel rule	Length measurement	Angled iron
3	Venier caliper	Measurement of the thickness of sheet metal	Welding electrode
4	scriber	Marking out the outline on sheet metal	Cutting disc
5	Bench vice	Holding metal workpieces for machining	Grinding disc
6	Impact drill	Drilling of holes on workpieces	
7	Portable grinding machine	Grinding welded and cut surfaces for a smooth finish	
8	Arc welding machine	Joining components together	
9	Disc cutter	Cutting metal workpieces	
10	Measuring tape	Measuring much longer lengths	
11	Digital tachometer	Measuring rotational speed	
12	Welding hammer	Brushing off the debris of weldment	

4.Results

4.1Performance analysis of the soybean threshing machine

Table 5 shows the performance metrics of the mechanical soybean thresher. The thresher has a throughput (capacity) of 81.2-96.4 kg/h within the speed range of the drum. The test results revealed that the machine has a high efficiency of 74.62-93.67% and a very low damage proportion (0.02-0.047). The implication is that users of the machine can thresh and winnow the produce (soybean) simultaneously with a very high overall output proportion. These results are an improvement in the efficiency of the thresher designed by [45], who obtained an efficiency of 93%.

Table 5 Performance metrics of the mechanical soybean thresher

Performance Metrics	Value
Capacity (kg/hr)	81.2 – 96.4
A threshed proportion of grain	0.74 – 0.97
Unthreshed proportion of grain	0.03 – 0.26
Damaged proportion of grain	0.02 -0.047
Threshing Efficiency (%)	74.62 –93.67

Figure 16 shows the relationship between the machine capacity and the operating speed of the thresher. From the graph, the thresher capacity increases as the operating speed of the threshing mechanism increases. This establishes a very strong correlation, with a correlation coefficient of 0.9 between these performance metrics. The implication is that the capacity of the machine is a function of the operating speed of the threshing mechanism. The predictive model developed for this analysis is such that; **Capacity = 0.0446[Speed] + 54.018**. The predictive model allows for precise and accurate decision-making during machine design because the model has a high coefficient of determination of 0.8041, unlike the work of researchers like [40,45,49], which did not establish how the performance metrics relate and how they influence the overall output of the machine.

Figure 17 illustrates the effect of thresher operating speed on the proportion of grain damage during the experiment. As the operating speed increases, the proportion of grain damage decreases until an optimum speed of 675-775 rpm is reached, at which the proportion of grain damage is 0.02. At this speed when the lowest grain damage is recorded, the performance of the machine is best. A further increase in operating speed beyond this range damages more grains. This implies that the thresher should be operated within this experimentally determined speed range to get optimum returns from the thresher.

Figure 18 demonstrates the grain damage proportion of soybean grains across varying operational speeds during the evaluation. The data unveils a median damage proportion of 2.7, with the interquartile range (IQR) from 2.45 to 2.95. The whiskers extend from a minimum of 2.0 to a maximum of 3.1. This shows that the grain damage proportions maintained a relative consistency across the tested speeds, with a close clustering around the median.

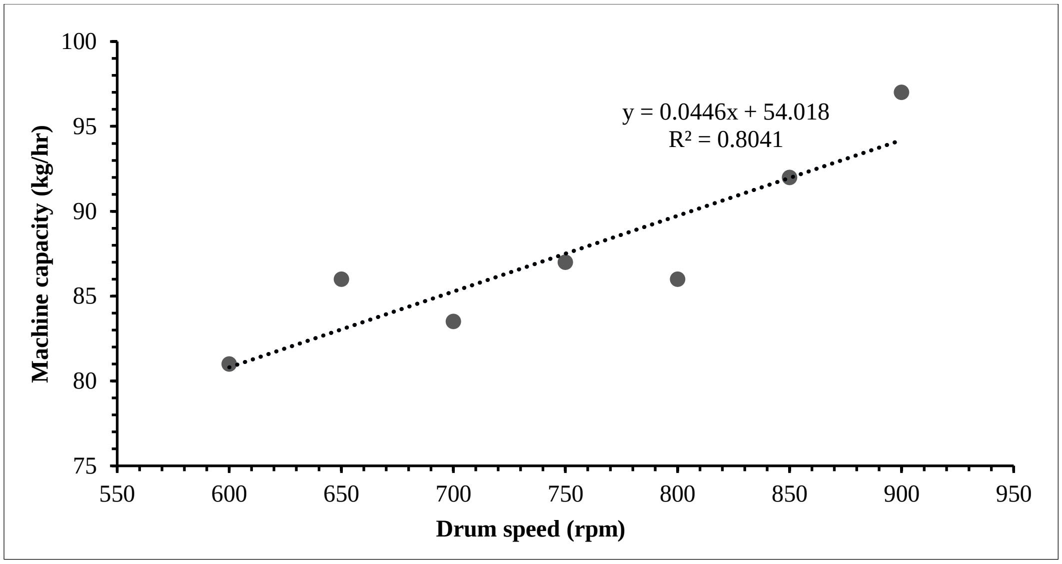

Figure 16 Influence of drum speed on the soybean thresher

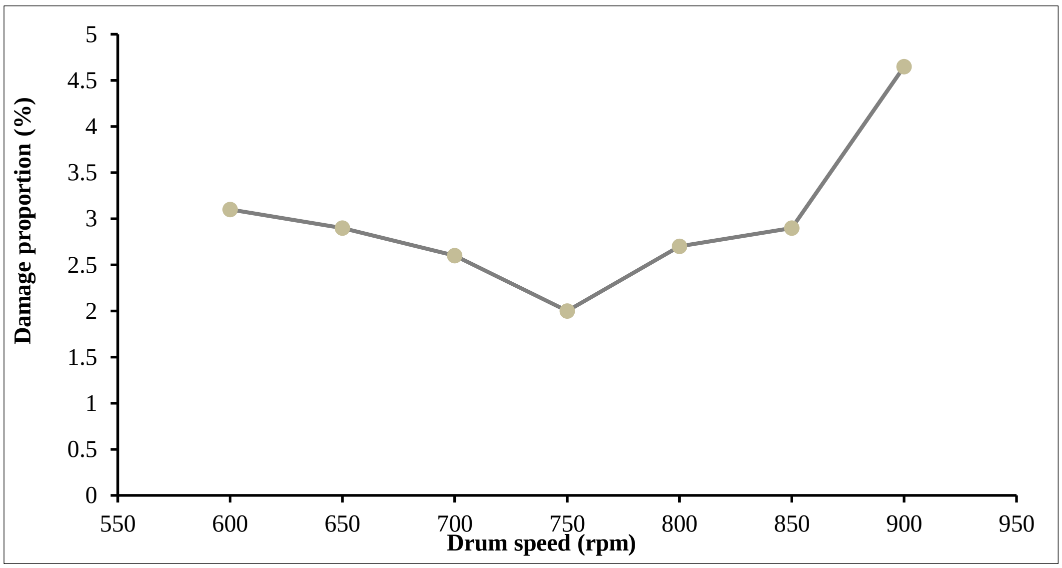

Figure 17 Effect of thresher operating speed on grain damage

Figure 19 is a graphical representation of the influence of the operating speed of the threshing mechanism on the threshing efficiency of the machine. The threshing efficiency increases as the thresher operating speed increases. This creates a very strong correlation, with a correlation coefficient of 0.85 between these performance metrics. The implication is that the efficiency of the machine is a function of the operating speed of the threshing mechanism. The predictive model developed for this analysis is such that; **Efficiency = 0.0633[Speed] + 38.843**. The predictive model allows for precise and accurate decision-making during machine design because the model has a high coefficient of determination of 0.7219. The efficiency of the soybean thresher was determined under varying operating speeds to allow for flexibility, unlike the work of researchers [24, 28, 33, 34], where the operating speed solely depended on the diameter of the output pulley selected.

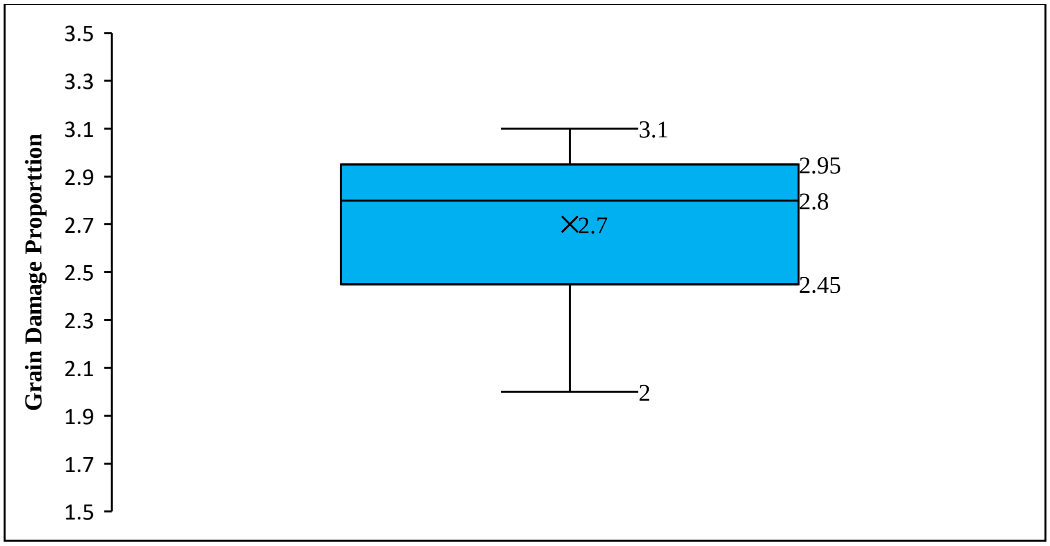

Figure 18 Boxplot analysis of grain damage proportion across various speeds

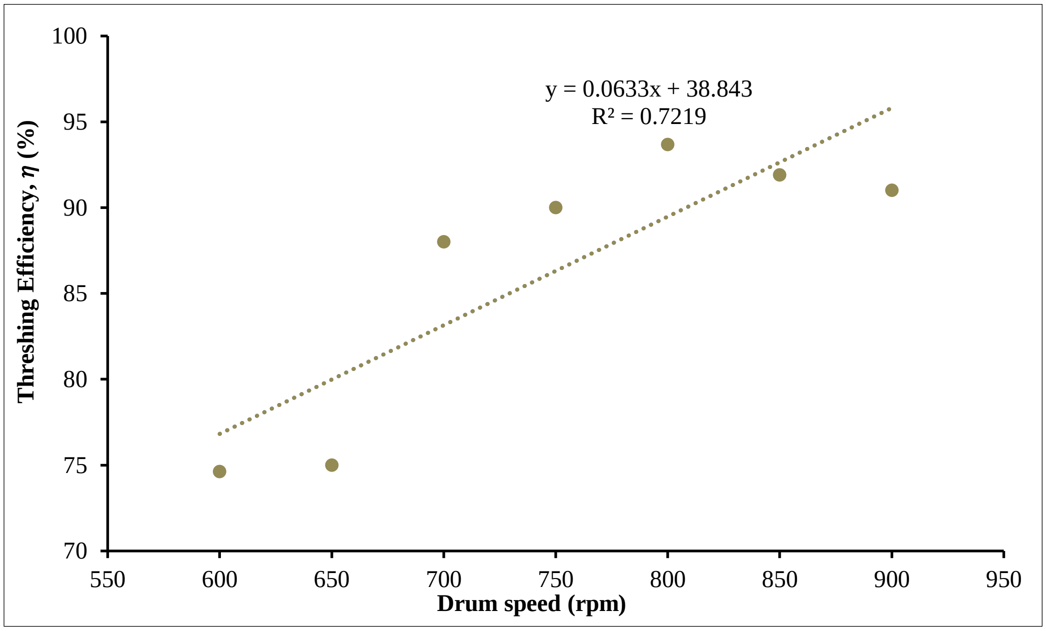

Figure 19 Influence of operating speed on thresher efficiency

5.Discussion

This study, which sought to develop a mechanical soybean thresher resulted in a completely functional machine with significant performance metrics. The design specifications were carefully computed, leading to a well-fabricated thresher that has a stable structure, is easy to use, and causes minimal user fatigue. The performance analysis showed a high-efficiency range of 74.62-93.67%, a very low damage proportion (0.02-0.047), and a throughput capacity range of 81.2-96.4 kg/h. These findings, which constitute an improvement are consistent with the report of [37], who obtained an efficiency of 75% but a better throughput capacity of 100 kg/h. The study additionally established a strong correlation between the machine's capacity and operating speed, and between the threshing efficiency and operating speed, having respective correlation coefficients of 0.9 and 0.85. The implication is that the machine developed by [37] was operated at a very high speed which produced a higher throughput relative to the machine developed for this study, and the lower efficiency recorded in the study of [37] is attributed to the very high yet suboptimal speed, which contributes to an increase in grain damage proportion.

The findings demonstrate that the designed and fabricated soybean thresher is efficient and effective in its intended function. The strong correlation existing between operating speed and both capacity and efficiency means that optimizing the speed of the threshing mechanism can improve the machine's performance. The developed predictive models, Capacity = 0.0446[Speed] + 54.018 and Efficiency = 0.0633[Speed] + 38.843 are important for precision in machine design, providing a high coefficient of determination, which emphasizes their reliability and accuracy. These predictive models are novel and exclusive to this study in the design and fabrication of threshers since they fill in a gap identified in the findings of researchers such as [37,39-40], where the throughput and efficiency were the only parameters determined as 85-92%, 115 kg/h; 75%, 100 kg/h and 85%, 140 kg/h respectively without relating them to the machine parameters. The implication is that this study has a relatively higher efficiency (74.62-93.67%) but a lower throughput (81.2-96.4 kg/h), and these variations are attributed to the operation of the machine for this study at optimal speed and the use of a fixed moisture content under the fractional factorial design methodology adopted for this study. Not only that but also, several other factors account for the variations recorded in the performance of the thresher. Operating speed, which is experimentally determined to be optimal for this study and hence leads to achieving a relatively higher efficiency. Material properties, like moisture content and soybean variety, can affect threshing effectiveness, where higher moisture potentially results in clogging. Operator influence is significant in affecting the desired output since experienced operators can adjust the loading rate for optimal performance, while inexperienced ones may struggle. In this study, the relatively lower throughput is attributed to operator influence. The low proportion of grain damage recorded (0.02-0.047) is particularly remarkable since it demonstrates the machine's ability to thresh soybeans well without causing much harm to the grains, which is necessary for maintaining the quality of the produce. The optimal operating speed range (750 -755 rpm) identified for minimal grain damage gives a proper comprehension of the machine's operational parameters, allowing users to obtain the best possible results.

The observed median grain damage proportion of 2.7 suggests moderate damage levels, consistent with the design and operational conditions of the threshing mechanism. The narrow IQR implies minimal variation in damage across the speed range, indicating that the machine operates uniformly within these parameters. Similar trends were reported in the work of [54], where soybean threshers operating within controlled speed ranges demonstrated damage proportions of 2.6–3.0, aligning with our findings. However, the maximum recorded damage (3.1) slightly exceeds the upper limit reported in their study, potentially attributable to differences in machine design or soybean variety. Conversely, studies like those by [55] found that damage proportions were significantly reduced (median = 2.2) when employing optimised rotor speeds and threshing clearances. This discrepancy suggests that further optimisation of the threshing parameters, particularly speed, could help minimise grain damage in our system.

The findings of this study have practical implications for all stakeholders including farmers, agricultural machinery manufacturers, and policymakers. For farmers, the high efficiency and low grain damage rate (0.02–0.047) minimizes postharvest losses, enhances soybean quality, and increases profitability. By processing larger volumes of soybeans in less time while maintaining quality, farmers can enhance productivity, especially in regions where soybean farming is economically crucial. The study also introduces predictive models for capacity and efficiency, which help manufacturers to design more efficient machines exclusive to specific needs, reducing costs and design time. The thresher's dual-functionality, that is, threshing and winnowing soybeans simultaneously, simplifies postharvest handling and reduces labour by promoting mechanization in regions like Ghana where manual threshing is still common. This shift to mechanized farming increases productivity, reduces reliance on manual threshing techniques, and makes soybean farming more viable on a larger scale. The mechanization also contributes to agricultural modernization, boosting local economies, improving food security, and fostering sustainable development. For policymakers, the adoption of such technologies can encourage investment in agriculture, improve food production systems, and support economic growth, particularly in developing countries.

Notwithstanding the good results obtained in this study, there are some limitations. The performance tests were conducted under controlled circumstances but testing in different environments is critical and crucial to validate the machine's success across diverse experimental settings. Also, the durability (long-term) and requirements for maintenance of the thresher were not considered and assessed but are factors that are critical for its prolonged use.

In contrast with previous studies, the developed thresher demonstrates improved performance metrics and gives a detailed analysis of the relationship between performance metrics and how they influence the overall output of the machine, unlike the works of researchers [27,38-40]. The strong correlations and accurate predictive models developed at a 5% significance level offer a detailed understanding of the machine's operational dynamics, which enhance more precise design and optimization.

The development of this mechanical soybean thresher offers a significant progression in agricultural machinery. The high efficiency, low grain damage of the machine, and its ability to process soybeans briskly and effectively underscores its potential effect on soybean farming. Whereas there are limitations that require attention through further research, the findings offer a good foundation for future enhancements and adoption to a large extent. This research contributes to the mechanization of agriculture, specifically in regions where manual processes are dominant. This machine can help promote agricultural productivity, improve the livelihoods of farmers, and also support food security initiatives.

A complete list of abbreviations is listed in *Appendix I.*

6.Conclusion and future work

The mechanical soybean thresher was designed, fabricated, and tested. From the results of the tests, the fabricated mechanical soybean thresher demonstrated functionality and ease of use under both load and no-load conditions. The stability of the thresher and the minimal fatigue and discomfort experienced by users indicate that the design is ergonomically friendly. Again, the thresher can achieve both threshing and winnowing concurrently, with a high overall output, having a throughput, threshing efficiency, and damage proportion of 81.2-96.4 kg/h, 74.62-93.67% and 0.02-0.047 respectively, representing an enhancement over previous designs. Also, careful consideration of the operating speed is critical for achieving optimal performance, with minimal grain damage. The study also revealed that the performance metrics have a strong correlation, where the relationship between the throughput and threshing efficiency versus speed have correlation coefficients of 0.897 and 0.85 respectively. A higher coefficient of determination (0.7219-0.8041) exists in making predictions with the models developed for this study.

From the study, it is recommended that further studies should explore the use of solar energy to power the thresher instead of conventional internal combustion engines due to the growing interest in sustainable and eco-friendly alternatives. The integration of renewable energy sources not only reduces the environmental impact but also addresses the energy needs of farmers in remote or off-grid areas. Future research should also focus on addressing the limitations of this study by conducting extensive testing to confirm the machine's performance in diverse agricultural contexts. Investigating the durability of the thresher and developing a maintenance protocol will ensure its sustained utility. Therefore, the use of the predictive models developed for this study in making decisions in engineering machinery design and development provides precise and accurate outcomes.

Acknowledgment

We extend our gratitude to Mr. Nathanial Kwashie-Madjrie for his invaluable role in producing the working drawings. Special thanks to Mr. Boakye Jeffrey Appiagyie for his dedicated efforts throughout the entire design and fabrication process of this machine. We also appreciate Mr. Ignatius Awutey Kwaku Xenyah, Ing. Joseph Aveyire, and all the Engineering Technicians at the machine shop of the Department of Agricultural and Biosystems Engineering, KNUST, Kumasi, Ghana, for their significant contributions and unwavering support to Team INJA during the machine's construction.

Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

None.

Author's contribution statement

Frederick Abangba Akendola: Conceptualization, design and modelling, fabrication, testing and evaluation, data analysis, writing – original drafting, review and proofreading. **Clement Adekunle Komolafe:** Writing – review, editing and proofreading. **Abdulai Ayirebi Ankrah:** CAD modelling and simulation. **Obed Ofori Yemoh:** CAD modelling and simulation.

References

[1] Mishra R, Tripathi MK, Sikarwar RS, Singh Y, Tripathi N. Soybean (glycine max l. merrill): a multipurpose legume shaping our world. Plant Cell Biotechnology and Molecular Biology. 2024; 25(3-4):17-37.
[2] Toomer OT, Oviedo EO, Ali M, Patino D, Joseph M, Frinsko M, et al. Current agronomic practices, harvest & post-harvest processing of soybeans (glycine max)-a review. Agronomy. 2023; 13(2):1-14.
[3] Uebersax MA, Cichy KA, Gomez FE, Porch TG, Heitholt J, Osorno JM, et al. Dry beans (phaseolus vulgaris L.) as a vital component of sustainable agriculture and food security-a review. Legume Science. 2023; 5(1):1-13.
[4] Addae-frimpomaah F, Amenorpe G, Denwar NN, Amiteye S, Adazebra GA, Sossah FL, et al. Participatory approach of preferred traits, production constraints and mitigation strategies: implications for soybean breeding in Guinea Savannah zone of Ghana. Heliyon. 2022; 8(5):1-14.
[5] Zhao Y, Liu J, Yang R, Guo T, Zhang J, Li W, et al. A comb-brushing-type green soybean pod harvesting equipment: design and experiment. Plos One. 2023; 18(11):1-28.
[6] Carreira VD, Aleixo EV, Ribeiro NM, Santos JD, Silva RP. A systematic and meta-analytical review of soybean mechanized harvesting in South America. Revista Brasileira De Engenharia Agrícola E Ambiental. 2023; 28(1):1-10.
[7] Staton MJ. Reducing soybean harvest losses. In encyclopedia of digital agricultural technologies 2023 (pp. 1109-19). Cham: Springer International Publishing.
[8] Karunathilake EM, Le AT, Heo S, Chung YS, Mansoor S. The path to smart farming: innovations and opportunities in precision agriculture. Agriculture. 2023; 13(8):1-26.
[9] Wamalwa PW. Optimization of design parameters and performance of a portable common beans (phaseolus vulgaris L) thresher. Doctoral Dissertation, Jomo Kenyatta University of Agriculture and Technology. 2022.
[10] Adekanye TA, Osakpamwan AB, Osaivbie IE. Evaluation of a soybean threshing machine for small scale farmers. Agricultural Engineering International: CIGR Journal. 2016; 18(2):426-34.
[11] Qabaradin A, Tsegaye A. A evaluation of soybean thresher for chickpea crop. Irish Interdisciplinary Journal of Science & Research. 2021; 5(2):101-8.
[12] Kang J, Wang X, Xie F, Luo Y, Li Q, Huang X. Experiments and analysis of the differential threshing cylinder for soybean with different maturities. Transactions of the Chinese Society of Agricultural Engineering. 2023; 39(1):38-49.
[13] Vejasit A, Salokhe V. Studies on machine-crop parameters of an axial flow thresher for threshing soybean. International: the GIGR Journal of Scientific Research and Development. 2004:1-12.
[14] Doddamani SS, Betageri SN. Influence of stages of harvesting and threshing methods on soybean [glycine max (L.) merrill]. The Pharma Innovation Journal. 2021; 10(6): 687-96.
[15] Ni Y, Jin C, Chen M, Qian Z, Yang T, Xu J, et al. Soybean crushing forms by mechanical harvesting and factors affecting the proportions of different forms. Food Science and Technology. 2023; 43:1-10.
[16] Cubukcu P, Şahar AK, Oluk CA, Onat FB. Soybean (glycine max L.) sprouts: an overview. MAS Journal of Applied Sciences. 2023; 8(3):581-90.
[17] Anderson EJ, Ali ML, Beavis WD, Chen P, Clemente TE, Diers BW, et al. Soybean [glycine max (L.) merr.] breeding: history, improvement, production and future opportunities. Advances in Plant Breeding Strategies: Legumes. 2019; 7:431-516.
[18] Amoah AE, Oppong AJ, Appah S, Obeng-akrofi G. Mechanised threshing of pod grains used as food and strategies to optimise the technique: a review. Journal of Advances in Agriculture. 2021; 12:30-43.
[19] Yamba P, Larson EA, Issaka Z, Akayeti A. Design, manufacture and performance evaluation of a soybean paddle thresher with a blower. International Journal of Mechanical Engineering and Applications. 2017; 5(5):253-8.
[20] Nag PK, Gite LP. Human-centered agriculture. Springer Singapore; 2020.
[21] Gautam PV, Mansuri SM, Prakash O, Pramendra, Patel A, Shukla P, et al. Agricultural mechanization for efficient utilization of input resources to improve crop production in arid region. In enhancing resilience of dryland agriculture under changing climate: interdisciplinary and convergence approaches 2023 (pp. 689-716). Singapore: Springer Nature Singapore.
[22] Li Y, Su Z, Liang Z, Li Y. Variable-diameter drum with concentric threshing gap and performance comparison experiment. Applied Sciences. 2020; 10(15):1-17.
[23] Tang Z, Zhang B, Wang M, Zhang H. Damping behaviour of a prestressed composite beam designed for the thresher of a combine harvester. Biosystems Engineering. 2021; 204:130-46.
[24] Warghane RS, Easwara PR. Efficiency enhancement of thresher by auto-controlling the cylinder clearance. International Journal of System Assurance Engineering and Management. 2023; 14(6):2066-79.
[25] Li X, Du Y, Guo J, Mao E. Design, simulation, and test of a new threshing cylinder for high moisture content corn. Applied Sciences. 2020; 10(14):1-20.
[26] Rudoy D, Egyan M, Kulikova N, Chigvintsev V. Review and analysis of technologies for harvesting perennial grain crops. In conference series: earth and environmental science 2021 (pp. 1-12). IOP Publishing.
[27] Delelegn T. Design development and performance evaluation of a common bean (phaseolus vulgaris) thresher. Doctoral Dissertation, Haramaya University. 2022.
[28] Guo J, Du Y, Wu Y, Mao E. Research status and development trend of corn harvester threshing device.

In ASABE annual international meeting 2019. American Society of Agricultural and Biological Engineers.
[29] Hunt D, Wilson D. Farm power and machinery management. Waveland Press; 2015.
[30] Dagur R, Singh D, Bhateja S, Rastogi V. Mechanical and material designing of lightweight high endurance multirotor system. Materials Today: Proceedings. 2020; 21:1624-31.
[31] Olusesi OS, Udoye NE. Development and characterization of AA6061 aluminium alloy/clay and rice husk ash composite. Manufacturing Letters. 2021; 29:34-41.
[32] Pereira T, Kennedy JV, Potgieter J. A comparison of traditional manufacturing vs additive manufacturing, the best method for the job. Procedia Manufacturing. 2019; 30:11-8.
[33] Adeyeye O, Sadiku ER, Osholana TS, Reddy AB, Olayinka AO, Ndamase AS, et al. Construction and evaluation of soybeans thresher. African Journal of Agricultural Research. 2019; 14(21):921-7.
[34] Ishola TA, Busari RA, Subair IO, Owoyemi IO, Issa AL. Development of an improved soybean thresher. Journal of Agricultural Engineering and Technology. 2021; 26(1):36-46.
[35] Asodina FA, Adams F, Nimoh F, Asante BO, Mensah A. Performance of smallholder soybean farmers in Ghana; evidence from upper west region of Ghana. Journal of Agriculture and Food Research. 2021; 4:1-7.
[36] Nair S, Suresh A, Mangat A. Gender friendly tools and equipments in farm mechanization. In engendering agricultural development 2022 (pp. 221-38). CRC Press.
[37] Hota S, Mishra JN, Mohanty SK, Khadatkar A. Design and development of pedal operated Ragi thresher for tribal region of Odisha, India. Agricultural Mechanization in Asia, Africa and Latin America. 2017; 48(4):71-5.
[38] Clearinghouse TA. Small-scale farm mechanization catalogue. Clearinghouse Technical Report Series 015. Cotonou, Benin: Technologies for African Agricultural Transformation, Clearinghouse Office, IITA; 2022:1-28.
[39] Harerimana L, Mishra IM, Kumar SP, Parray RA, Lande SD, Bandyopdhayaya K, et al. RSMSOMT response surface methodology optimization of operational and machine parameters of solar powered multicrop thresher on soybean. Agricultural Engineering International: CIGR Journal. 2024; 26(1):115-27.
[40] Yogaraj D, Subesh T, Devaraj A, Chowdary KS, Khakha U, Alone SP, et al. Design and analysis of compact paddy harvester machine. Materials Today: Proceedings. 2022; 62:1430-4.
[41] Lee GH, Moon BE, Basak JK, Kim NE, Paudel B, Jeon SW, et al. Assessment of load on threshing bar during soybean pod threshing. Journal of Biosystems Engineering. 2023; 48(4):478-86.
[42] Harerimana L. Studies on design and development of solar powered multicrop thresher for small holdings. Doctoral Dissertation, Division of Agricultural Engineering ICAR-Indian Agricultural Research Institute, New Delhi. 2022.
[43] Ma L, Xie F, Liu D, Wang X, Zhang Z. An application of artificial neural network for predicting threshing performance in a flexible threshing device. Agriculture. 2023; 13(4):1-15.
[44] Hanna HM, Quick GR. Grain harvesting machinery design, handbook of farm, dairy and food machinery (Kutz M, ed). William Andrew Inc, Delmar, NY; 2007.
[45] Chandra RJ, Masilamani P, Suthakar B, Rajkumar P, Sivakumar SD, Manonmani V. Effect of moisture content on combine harvested seed crop and its quality. Journal of Experimental Agriculture International. 2024; 46(3):114-38.
[46] Mussema R, Diro S, Erko B, Desalegn T, Teshale D, Wake RD, et al. Soybean value chain analysis in Ethiopia: a qualitative study research. Research Report Number-134, EIAR. 2022.
[47] Wang F, Liu Y, Li Y, Ji K. Research and experiment on variable-diameter threshing drum with movable radial plates for combine harvester. Agriculture. 2023; 13(8):1-16.
[48] Marina I, Sujadi H, Indriana KR. Optimizing soybean cultivation efficiency through agricultural technology integration in plant monitoring system. Greenation International Journal of Engineering Science. 2023; 1(2):115-27.
[49] Lal S, Jogdand SV, Naik RK, Koumary NK. Comparative evaluation of performance of traditional method and commercially available pedal operated paddy thresher with the developed machine. Journal of Scientific Research and Reports. 2024; 30(8):647-55.
[50] Prabakaran MP, Kannan GR. Optimization of laser welding process parameters in dissimilar joint of stainless steel AISI316/AISI1018 low carbon steel to attain the maximum level of mechanical properties through PWHT. Optics & Laser Technology. 2019; 112:314-22.
[51] Spotts MF, Shoup TE, Hornberger LE, Kazmer DO. Design of machine elements. Journal of Mechanical Design. 2004; 126(1):201.
[52] https://extension.sdstate.edu/about/our-experts/sdsu-extension. Accessed 26 December 2024.
[53] Martey E. Soil fertility management and economics of soybean in Ghana. Doctoral Dissertation, University of Illinois at Urbana-Champaign. 2019.
[54] Ilori TA, Dauda TO, Adewumi IO. Machine crop parameters' model of spike-tooth thresher for soybean. World. 2020; 8(3):97-104.
[55] Liu P, Jin C, Liu Z, Zhang GY, Cai ZY, Kang Y, et al. Optimization of field cleaning parameters of soybean combine harvester. Transactions of The Chinese Society of Agricultural Engineering. 2020; 36:35-45.

Frederick Abangba Akendola is a Lecturer and a PhD candidate in Mechanical Engineering at the University of Mines and Technology, Tarkwa, Ghana. He holds a BSc in Agricultural Engineering and an MPhil in Mechanical Engineering, both from the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. He has specialized in Design and Manufacturing, Hydraulics, and Renewable Energy Technology. He is currently working on Artificial Intelligence application for mechanical systems for performance improvement. He is a member of the Ghana Institution of Engineering (GHIE) and Ghana Society of Agricultural Engineering (GSAE).
Email: faakendola@umat.edu.gh

Clement Adekunle Komolafe is a Senior Lecturer at the Department of Mechanical Engineering, University of Mines and Technology, Tarkwa, Ghana. He holds a Ph.D. degree in Mechanical Engineering (Thermofluids) from the Federal University of Agriculture, Abeokuta, Nigeria. His areas of research focus include Thermal Engineering (Thermodynamics, Fluid Mechanics, and Heat and Mass Transfer), Energy Technologies and Machine Design. He has been serving as a reviewer to many reputable international Journals. Professionally, he is a Council for the Regulation of Engineering in Nigeria (COREN)-certified Mechanical Engineer, a Member of the Nigerian Society of Engineers (MNSE), and a Member of the Nigerian Institution of Mechanical Engineering (MNImechE).
Email: cakomolafe@umat.edu.gh

Abdulai Ayirebi Ankrah is a Lecturer and a Ph.D. candidate in the Mechanical Engineering Department at the University of Mines and Technology. He holds an M.Sc. in Mechanical Engineering from the Pan African University Institute and a B.Sc. in Mechanical Engineering from the University of Mines and Technology. His areas of specialization include Design and Manufacturing, Modeling and Fault Detection, Condition Monitoring, Diagnosis, and Prognostics.
Email: aaankrah@umat.edu.gh

Obed Ofori Yemoh was born on January 13, 1988, in Accra, Ghana. He holds a Higher National Diploma in Plant Engineering from Accra Technical University, a Bachelor's Degree in Mechanical Engineering (Design and Manufacturing) from KAAF University College, and a Master of Philosophy in Mechanical Engineering (Design and Manufacturing) from Kwame Nkrumah University of Science and Technology (KNUST). He is a member of the National Association of Black Engineers and currently serves as an Assistant Lecturer in the Department of Mechanical Engineering at the University of Mines and Technology. He brings extensive expertise in design, manufacturing, and plant engineering to his professional work. His research interests include the Design and Manufacturing of Plant and Industrial Equipment, Product Design and Development, Sustainability, and Green Building Technology. In addition to academia, he is a professional Design Engineer with over 10 years of experience in Engineering Design and Detailing.
Email: ooyemoh@umat.edu.gh

Appendix I

S. No.	Abbreviation	Description
1	AI	Artificial Intelligence
2	BOM	Bill of Materials
3	CAD	Computer-Aided Design
4	CNC	Computer Numerical Control
5	CSIR-CRI	Council for Scientific and Industrial Research-Crop Research Institute
6	DOE	Design of Experiment
7	FEA	Finite Element Analysis