Design and evaluation of crop residues shredder

Seth Osei[1], Francis Kumi[1*], Joseph Kofi Conduah[1], Hans Fumba Murangaza[1,2], Karimu Abdulai[1,3]

(1. Department of Agricultural and Mechanical Engineering, School of Sustainable Engineering, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast Ghana;
2. Faculty of Agriculture, Catholic University of Bukavu, Democratic Republic of Congo;3. Department of Agricultural Engineering, School of Engineering, University for Development Studies, Nyankpala campus, Tamale, Ghana).

Abstract: The study aimed to design and evaluate a crop residues shredder. The components of the machine include a frame, a hopper, shafts, an electric motor, blades, a sieve, a spur gear, and an outlet. The performance of the developed machine was evaluated using maize, millet and sorghum stalks as feeding materials, and under varying speeds of 0.4 m s^{-1}, 0.8 m s^{-1} and 1.6 m s^{-1}. When operated at 1.6 m s^{-1}, the machine achieved maximum shredding efficiencies of 82.5%, 79.2% and 77.5% for maize, millet and sorghum respectively. At the same speed of 1.6 m s^{-1}, a maximum throughput capacity of 14.6 kg h^{-1} with maize stalk was obtained, while a minimum of 4.8 kg h^{-1} was recorded with the sorghum stalk at a speed of 0.4 m s^{-1}. Furthermore, while sorghum stalks required more shredding energy, a general trend of increasing power consumption and longer operation time was observed with decreasing shredding speeds for all crop residues. Additionally, it was found that the particle size distribution depended on the feedstock, with sorghum residues exhibiting the highest sieve retention (71%–82% on 2 mm–4 mm sieves), followed by millet (45.5%–47.5%) and maize (44.1%–57.5%). Additionally, operating the machine at the highest speed (1.6 m s^{-1}) generated much finer particles which could facilitate rapid decomposition. The machine is user-friendly and adaptable to smaller scale farmers for carrying crop residues size reduction operations in Ghana and other sub-Saharan Africa countries.

Keywords: crop residues, shredder, shredding efficiency, particle size distribution.

Citation: Osei, S., F. Kumi, J.K. Conduah, H. F. Murangaza, and K. Abdullai. 2026. Design and evaluation of crop residues shredder. Agricultural Engineering International: CIGR Journal, 28(1):123-134.

1 Introduction

An agricultural waste refers to any by-product emanating from the cultivation and processing of agricultural crops and livestock including fruits, vegetables, meat, poultry, and other dairy products (Nande et al., 2023). Agricultural intensification leads to increasing amount of waste creating disposal challenges and environmental concerns (Jena and Singh, 2022).

Agriculture is the most dominant economic activity in Ghana. This extensive farming activity generates large quantities of crop residues during harvest and processing, including stalks, leaves, husks, and shells. However, effective management and valorisation of these residues remain challenging for farming communities (Patil et al., 2024). Meanwhile, it has been reported by Antwi-Agyei et al. (2023) that there is scarcity of crop residues for conservation agriculture practices in small farm holdings in the

---

Received date: 2025-03-17 **Accepted date:** 2025-08-13

***Corresponding author: Francis Kumi.** Associate Professor, Department of Agricultural and Mechanical Engineering, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast. Ghana. Tel: +233-553135913. Email: francis.kumi@ucc.edu.gh.

northern part of the country, which necessitates the development of alternative techniques to support sustainable production. This is largely because farmers often resort to the practice of open-air burning of these residues which tend to rather release pollutants into the atmosphere, contributing to greenhouse gas emissions. The combustion of agricultural residues, such as stubble burning, releases smoke and soot particles that pose significant risks to human health and soil quality. These emissions can lead to the depletion of essential nutrients in the soil ultimately affecting agricultural productivity and ecosystem health (Pradhan et al., 2024). Properly managing crop residues through recycling for conservation agriculture or nutrient resource utilization technologies can greatly improve soil fertility, enhance soil health, and decrease the reliance on synthetic fertilizers (Yadvinder-Singh et al., 2022).

One approach is the utilization of crop residues shredders to facilitate size reduction of residues into relatively smaller particles for subsequent composting or direct field applications. These machines are often developed to chop the materials obtained after harvest such as corn stalks and wheat straw (Dattatraya Raut and Bhalgat, 2020). The shredding process offers a significant benefit by enhancing the nutrient content of the soil during the initial decomposition stages when the shredded materials are applied to the soil. Shredded crop residues leave a significant amount of essential nutrients (Udakwar and Sarode, 2023) as they are often nutrient-rich, containing nitrogen, phosphorus, sulphur, and potassium, making them valuable for agricultural use. Nevertheless, the challenge persist as crop residues shredders are mostly unavailable to smallholder farmers in Ghana and sub-Sahara Africa and there are limited research reports on the development of crop residues shredders tailor-made for smallholder farmers in the sub-region who cultivate more than 80% of farmlands in Africa and Asia (Fan and Rue, 2020). In areas where shredders exist, they are not patronised by smallholder farmers due to the high costs, large power requirements, and other design considerations unsuitable for rural farmers (Ramulu et al., 2023).

The objective of this study was therefore to design and fabricate a crop residues shredder machine tailored for smallholder farmers and asses its performance in terms of efficiency, throughput capacity, power consumption, and the particle size of the shredded crop residue.

2 Materials and methods

2.1 Materials

The materials for the fabrication of the crop residues shredder were selected based on availability, durability and cost effectiveness. The main materials include mild steel plates (which are low-carbon steel sheets with tensile strength of 400-550 MPa, good weldability and ductility), angle irons (are L-shaped structural steel with high strength-to-weight ratio and tensile strength of 400-600 MPa, providing excellent load-bearing capacity for framework), and cast steel (which is a molten steel poured into moulds to create complex shapes, offering tensile strength of 485-620 MPa with uniform properties throughout and the ability to be heat-treated for enhanced performance for the blades and spacers as well as steel pipes). To complete the assembly, several essential components were incorporated, including pillow bearings, a spur gear, an electric motor (2.24 kW), bolts and nuts. Electric arc welding and drilling machines as well as tools such as vernier callipers, tape measure, try square, hammer, centre punch and hacksaws were used for the fabrication processes. A five standard sieve device was used for analysing the particle size distributions of the shredded materials.

2.2 Methods

2.2.1 Design considerations

In designing the shredder, the primary mechanical factors considered were the strength, rigidity, and the simplicity of the materials to be used for fabricating the machine. Furthermore, the aspect of using a motor with speed range that would not produce too much noise and vibration was considered alongside the ability of the key shredding mechanism to carry the shredding as uniformly as possible. On the other hand, it was ensured that the materials used are locally sourced and readily available for fabrication, and of low fabrication costs. In the fabrication process, critical factors such as ease of operation, ergonomics (ease of feeding with raw materials and collection of shredded materials), and minimal maintenance cost, were taken into consideration.

2.2.2 Design analysis

2.2.2.1 Determination of the volume of the hopper

The shape of the hoppers is trapezoidal, and the following formulae were used for the design calculation (Waghmare et al., 2022):

$$A_1 = L_1 \times W_1 \tag{1}$$

Where,

A_1 = area of the top rectangle (m^2);

L_1 = length of the top opening (M);

W_1 = width of the top opening (m).

$$A_2 = L_2 \times W_2 \quad (m^2) \tag{2}$$

Where,

A_2 = area of the bottom base (m^2);

L_2 = length of the bottom base (m);

W_2 = width of the bottom base (m).

$$\text{Volume of the hopper (V)} = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 \text{ x } A_2}\right) \quad (m^3) \tag{3}$$

Where,

h = height of the hopper (m).

2.2.2.2 Power transmission

The selected crop residues shredder concept chosen for the machine showed it was to be powered by an electric motor. The motor provides the necessary power to drive the cutting mechanism to cut or slice the residues into small pieces. Power transmitted by shaft was determined as Abdulkadir et al. (2020):

$$P = F \times V \tag{4}$$

Where,

P = power (W);

F = force of shredding (N);

V = velocity (ms^{-1}).

The force required to shred was determined using the following equation:

$$F = m\omega^2 r \tag{5}$$

Where,

F = force required to shred the crop residue (N);

m = mass of shredding blades (kg);

ω = angular velocity of the shaft (rad s^{-1});

r = Radius (m).

$$\omega = \frac{2\pi N}{60} \tag{6}$$

Where,

N is the speed of shredding (rpm).

The power delivered by the shaft is given by:

$$P = F\omega r \tag{7}$$

2.2.2.3 The Shaft diameter

The diameter of the machine's shafts was estimated using the maximum shear stress theory, according to Khurmi and Gupta (2005), is suitable for shafts experiencing combined bending and twisting moments. The shaft was made from tough mild steel and the following formula was used to determine its size:

$$d^3 = \frac{16}{\pi\, Ss}\sqrt{(kt \times mt)^2 + (kb \times mb)^2} \tag{8}$$

Where,

d = diameter of the shaft (mm);

Ss = Allowable shear stress of metal with key (Nmm);

mb = maximum bending moment (Nmm) ;

mt = torsion moment (Nmm) ;

kb = combined shock and fatigue factor applied to bending moment;

kt = combined shock and fatigue factor applied to torsional moments.

The shredder shaft was to rotate within the shredder chamber and loaded with blades and spacers. These blades were arranged on the shaft with the spacers to allow the shredding of the crop residues materials.

2.2.2. 4 Factor of safety

The machine's design integrity was verified by ensuring the factor of safety exceeds 1, which guarantees the machine will not structurally fail under load. Here, 'FoS' is the factor of safety, 'YS' represents the yield strength of the material used, and 'WS' denotes the working stress or the maximum stress. The computation was performed using the equation

(Abdulkadir et al., 2020) below:

$$FoS = \frac{Y_S}{W_S} \tag{9}$$

2.3 Machine description

The main components of the shredder are presented in Table 1 with the isometric drawing shown in Figure 1. The machine operated with a variable speed electric motor with a maximum operating speed of 1.6 m s^{-1}. The machine weighed approximately 110 kg with maximum hopper volume of 0.01478 m^3.

Table 1 Machine components description

Item No.	Name of the component	Description	Quantity.
1	Frame	Mild Steel angle iron	1
2	Hopper	Mild Steel Plate	1
3	Blades	Mild Steel	16
4	Shafts	Mild Steel	2
5	Spacer	Mild Steel	16
6	Outlet/Discharge	Mild Steel (Steel metal)	1
7	Spur Gear	Aluminum Alloys	2
8	206 Pillow Bearing	Cast Steel	4
9	Electric Motor	2.24 kW, 1350 rpm	1
10	M10 Bolt and nuts	Mild Steel	13
11	M8 Bolts and nuts	Mild Steel	8
12	Sieve	Mild steel	1
13	Guard	Mild steel	1
14	Coupling	Mild steel	1

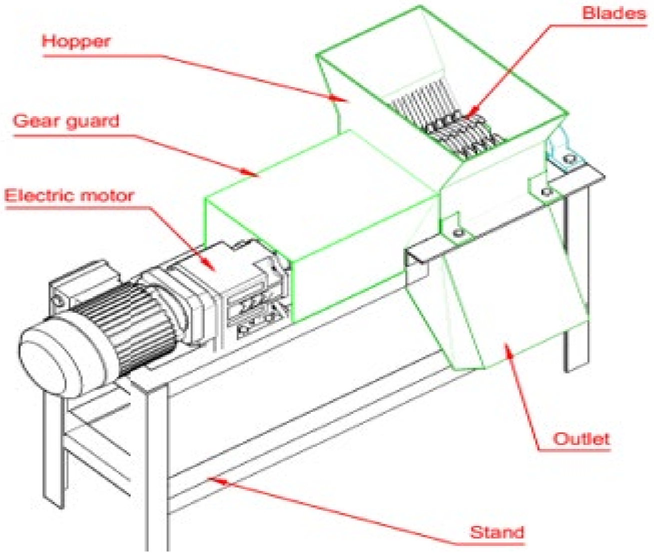

Figure 1 Isometric view of the shredder

2.4 Machine fabrication

The various components of the shredding machine were fabricated in a Ghanaian workshop in Cape Coast in the Central Region of Ghana which lies between longitude 1°15W and latitude 5° 06N at an altitude of 1.1 meters above sea level. The primary machinery used included an electric arc welding machine for joining components, a drilling machine for creating necessary holes, and an electric hand grinding machine for finishing work. Other arrays of hand tools were also used to ensure accurate measurements and proper assembly. These tools included vernier callipers for precise measurements, a tape measure for longer dimensions, a try square for checking angles, spanners for fastening, a hacksaw for cutting, hammers for work, and a centre punch for marking drilling points. The components of the shredder were assembled as shown in Figure 2.

2.5 Performance evaluation of the manufactured crop residues shredder

The crop residues shredding machine was evaluated to assess its performance terms of shredding efficiency, power consumption and throughput capacity. A factorial arrangement in completely randomized design (CRD) was used as experimental design for the study. The two factors tested were: crop residues and operation speed, each with three levels. The three crop residues used were maize stalk, sorghum stalk, and millet stalk, while of the speeds (converted from rotational to linear speeds) were 0.4 m s^{-1}, 0.8 m s^{-1}, and 1.6 m s^{-1}. There were nine (9) treatment combinations, and each was replicated three times, resulting in a total of twenty-seven (27) runs.

Figure 2 Manufactured crop residues shredder

2.5.1 Moisture Content

The moisture content was determined on samples from the stalks of the three different crop residues selected. These samples were weighed and recorded before being placed in an oven at a temperature of 105°C for 24 hours (Bergman, 2021). After drying, the samples were weighed again, and the moisture content was determined using the following formula:

$$\text{Moisture content} = \frac{\text{Initial weight } - \text{final weight}}{\text{Initial weight}} \times 100\% \qquad (10)$$

2.5.2 Shredding efficiency

The shredding efficiency was determined by using the following formula (Abdulkadir et al., 2020):

$$\text{Shredding efficiency} = \frac{\text{weight of output crop residue shreded (kg)}}{\text{weight of input crop residues (kg)}} \times 100\% \qquad (11)$$

$$\text{Throughput capacity} = \frac{\text{weight of shredded crop residue (kg)}}{\text{Time taken to shred the crop residue (h)}} \qquad (12)$$

2.5.3 Power consumption

The power consumption was determined by the device's power and the duration of operation.

The formula (Al-Ogaili et al., 2021) to calculate the power usage in kilowatt-hours (kW h) is:

$$\text{Energy (kWh)} = \text{Power(kW)} \times \text{Time (h)} \qquad (13)$$

2.5.4 Particle size distribution

The particle size distribution was evaluated using five standard sieves (of sizes 0.25, 0.425, 1.18, 2, and 4 mm) and a bottom pan to collect the remnants passing through the fifth sieve. The sieves were organized in descending order, from the largest to the smallest in hole sizes (in millimetres). An average weight of 100 g was recorded for all the samples prior to sieving. The sample was placed into the first sieve, covered with its lid, and manually shaken for 10 minutes. The particles retained in each sieve were then weighed, and the data documented (Gee and Or, 2002).

2.6 Statistical analysis

The data collected on shredding efficiency, shredding time, and throughput capacity during the evaluation were analysed using the 2021 version of Minitab statistical software. The data was subjected to an analysis of variance (ANOVA), with means separated at a 5% significance level. Where differences exist, the Tukey HSD test was used to separate the means. Also, basic statistical methods in Microsoft Excel (2020), which involved calculating the percentages, means and plotting graphs were done.

3 Results and discussion

3.1 Performance evaluation of the shredder

The machine's performance was evaluated using three agricultural residues: maize stalk, millet stalk, and sorghum stalk. The result includes shredding efficiency, throughput capacity, time duration, and power consumption.

3.1.1 Shredding efficiency

In Figure 3, the results of the shredding efficiency are presented. It indicates that shredding performance improved markedly with increasing speed of the motor. At 1.6 m s^{-1}, the maize stalks achieved the highest efficiency of 82.5%, followed by millet (79.2%) and sorghum (77.5%). The relationship between shaft speed and the shredding efficiency is consistent with the findings of Mathanker et al. (2015), who indicated that higher speeds applied tend to increase the mechanical forces, thereby enhancing shredding efficiency. This agrees with the results of Abdulkadir et al. (2020) who observed a maximum efficiency of 93% at a much higher speed (approximately 7.15 m s^{-1}). It was observed that while the type of crop residue and speed were found to be statistically significant ($p<0.05$), the interaction effect was not statistically significant ($p>0.05$), which suggests that crop-specific physical properties of the materials and speed individually are keys to determining the efficiency of shredders as reported by Busari et al. (2024). Notably, the shredding efficiency is dependent on the type of material used and the operational speed of the machine.

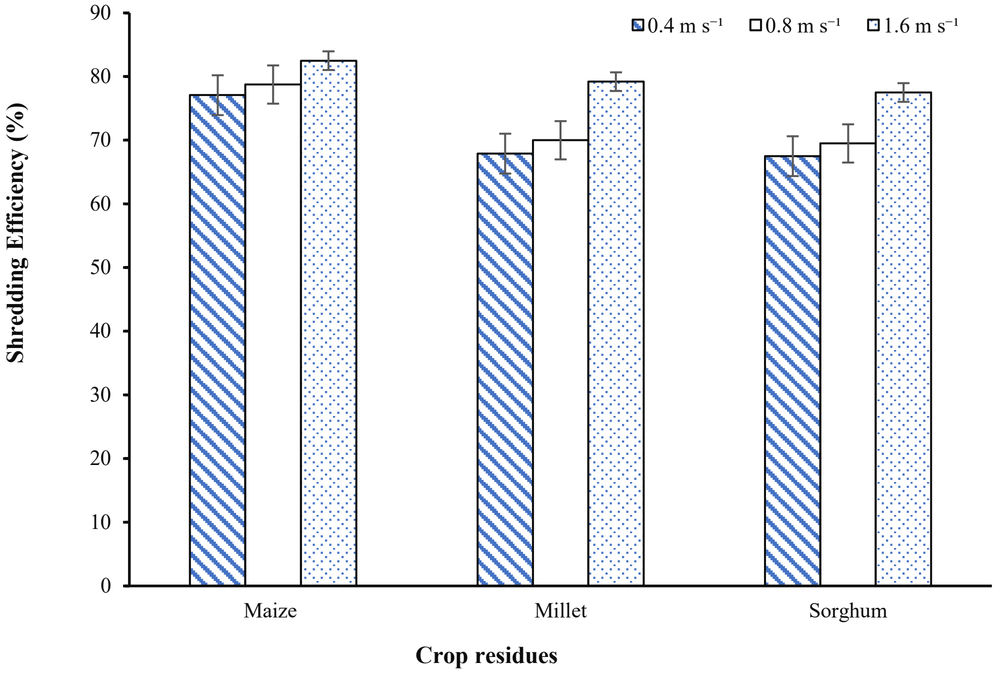

Figure 3 Shredding efficiency (%) of different residues under varying speeds

3.1.2 Shredding time

Figure 4 shows that the speed of processing had a significant inverse relationship with shredding time across all crop types. As the speed increased, the time required for shredding decreased substantially. At the lowest speed of 0.4 m s^{-1}, sorghum recorded approximately 600 seconds, millet 520 seconds, and maize 440 seconds. When the speed was increased to 0.8 m s^{-1}, both millet and maize processing times reduced to approximately 260 seconds. The statistical analysis showed that both crop type and speed had significant effects on processing time ($p<0.05$). However, there was no significant interaction effect between these variables ($p>0.05$), indicating that speed changes affected all crop types similarly. These findings align with recent research by Pintens et al. (2023) and Awgichew (2020) who emphasized the importance of variable speed capabilities in shredder design. The results also support the work of Jančík et al. (2022) who concluded that higher speeds improve shredding efficiency. Nevertheless, the consistently longer processing times for sorghum, at all speeds, reinforces observations by Awgichew (2020) and Salo et al. (2021) that the inherent properties of the crop material significantly influence processing efficiency and time.

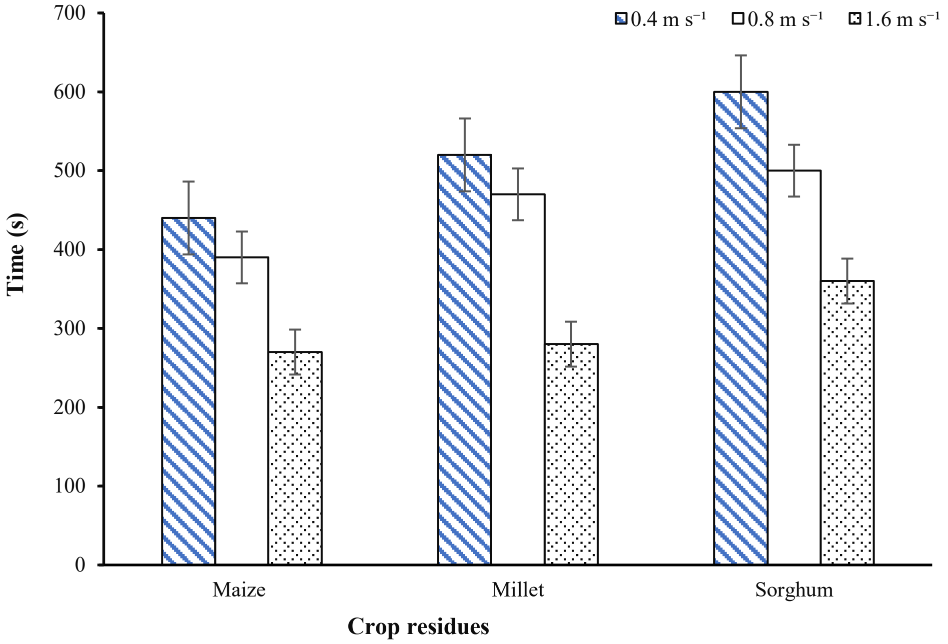

Figure 4 Time for shredding of different residues under varying speeds

3.1.3 Shredder's throughput capacity

The throughput capacity of the machine was tested and the results illustrated in Figure 5. The results shows that the higher the speed of operation, the higher the throughput capacity. At the highest speed of 1.6 m s^{-1}, the shredder was able to shred 14.4 kg h^{-1} of maize stalk which was the highest followed by millet stalk 14 kg h^{-1} while at the lowest speed of 0.4 m s^{-1} was 4.8 kg h^{-1} which was sorghum stalk. These results agree with previous research by Awgichew (2020) who found that higher speeds enhance throughput by reducing frictional resistance in the shredder mechanism.

3.1.4 Shredder's power consumption

From figure 6, the power consumption decreased as speed increased, with maize requiring 0.20 kWh at 0.4 m s^{-1} but only 0.10 kWh at 1.6 m s^{-1}. Millet on the other hand required 0.25 kWh at 0.8 m s^{-1} but only 0.1 kWh at 1.6 m s^{-1}. Sorghum, however, consistently demanded more energy, consuming 0.26 kWh at 0.4 m s^{-1} and 0.14 kWh at 1.6 m s^{-1}. This trend reflects how prolonged shredding times at lower speeds lead to higher power usage aligning with findings that extended processing times significantly could affect energy consumption in machinery operations as noted by Beniak et al. (2012). The type of material being shredded also affects energy consumption, as different materials exhibit varying mechanical and physical properties that influence the energy required for shredding as stated by Li et al. (2013) .

3.2 Particle size distribution of shredded crop residues

3.2.1 Particle size distribution at 0.4 m s^{-1}

Figure 7 below depicts the analysis of particle size distribution for crop residues (maize, millet, and sorghum). At 0.4 ms^{-1}, a unique pattern of increasing weight percentage with increased particle size was observed across all crops, particularly within the critical 2-4 mm range. Sorghum exhibited the highest retention at 82% (4 mm), followed by maize (55%) and millet (45%), reflecting the distinct structural properties of each crop residue and their implications for composting potential and crop production. According to Li et al. (2021) particle size of 2 mm promote organic matter degradation because they provide a balance of surface area and porosity, essential for microbial activity and adequate aeration.

The observed trend aligns with the findings of Stetson et al. (2018), who noted that larger particle sizes contribute to improved soil structure over time by decomposing gradually and sustaining microbial communities longer. This slow decomposition aids in nutrient retention, crucial for improving soil health, as noted in the work of Stegarescu et al. (2020) which emphasizes that long-term benefits of larger particle sizes enhance soil aggregate stability and microbial biodiversity.

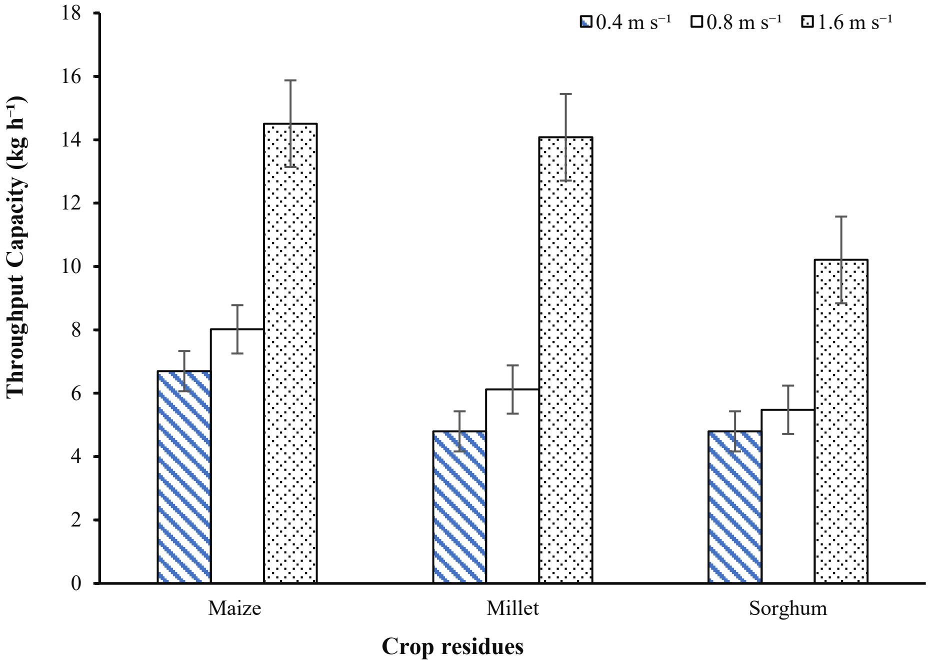

Figure 5 Throughput capacity of different residues under varying speeds

3.2.2 Particle size distribution at 0.8 m s^{-1}

Figure 8 shows the particle size distribution of shredded crop residues (maize, millet, and sorghum stalks) at a shredding speed of 0.8 m s^{-1}. As the particle size increased, the weight percentage (%) increased for all three crop residues. At a particle size of 4 mm, 71% of shredded sorghum stalks were retained, followed by 67.5% for millet and 57.5% for maize. The trend towards medium-sized particles is consistent with the observations of Jagadabhi et al. (2019), who reported that uniform, medium particles enhance microbial activity due to improved aeration and facilitate faster composting cycles. This distribution reflects a balance between stability and breakdown, allowing particles to resist compaction and maintain air channels within the compost pile (Ahn et al., 2024). Such structure is particularly beneficial for residues that will decompose in mid-length composting durations, as they allow for moderate microbial interaction while preserving bulk.

3.2.3 Particle size distribution at 1.6 m s^{-1}

The Figure 9 below expresses the size distribution of the particles at a shredding speed of 1.6 m s^{-1}. It resulted in significant differences ($p<0.05$) among the stalks at different sieves mesh size. It resulted in a further shift toward smaller particles, especially with maize, where a higher proportion of residues passed through finer sieves. At this highest speed, sorghum continued to produce relatively larger particles (81.4% at 4 mm), while millet and maize exhibited smaller particle sizes, with 57.7% and 44.1% at 4 mm, respectively. Studies by Ruan et al. (2023) has shown that reducing the initial particle size promotes aerobic breakdown and increases the rate of organic matter degradation, leading to quicker nutrient availability in soils. This rapid breakdown is beneficial for short-term composting needs, although it may immobilize nitrogen initially, as observed by Stetson et al. (2018). Fine particles are useful for short-term composting and application where faster decomposition rates are necessary, though they might require nitrogen supplementation for balance due to rapid mineralization.

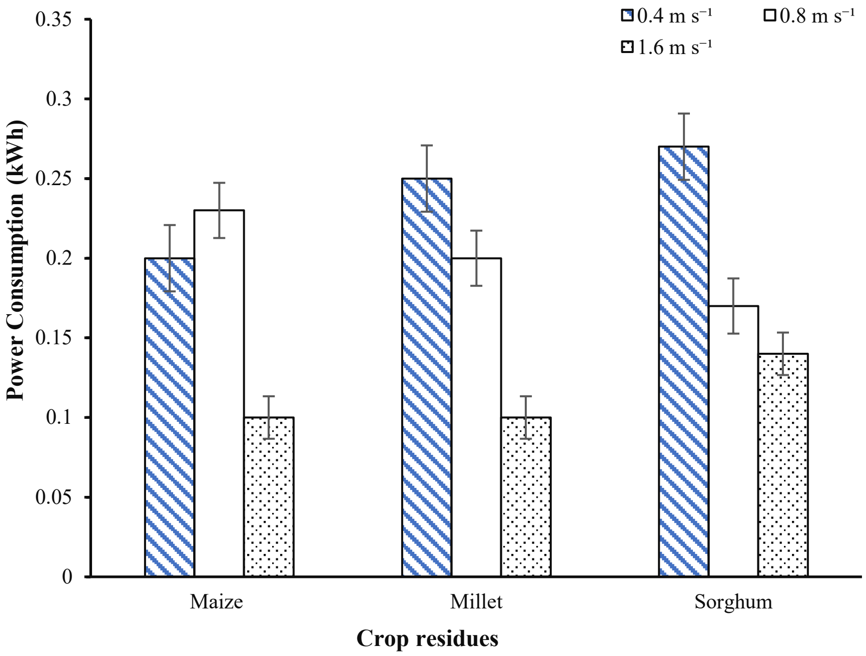

Figure 6 Power consumption of different residues under varying speeds

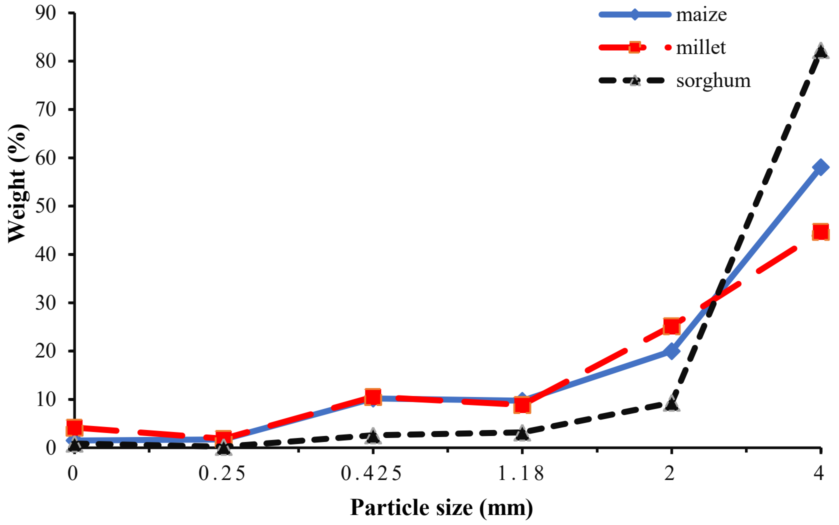

Figure 7 Particle size distribution of crop residues at the speed of 0.4 m s^{-1}

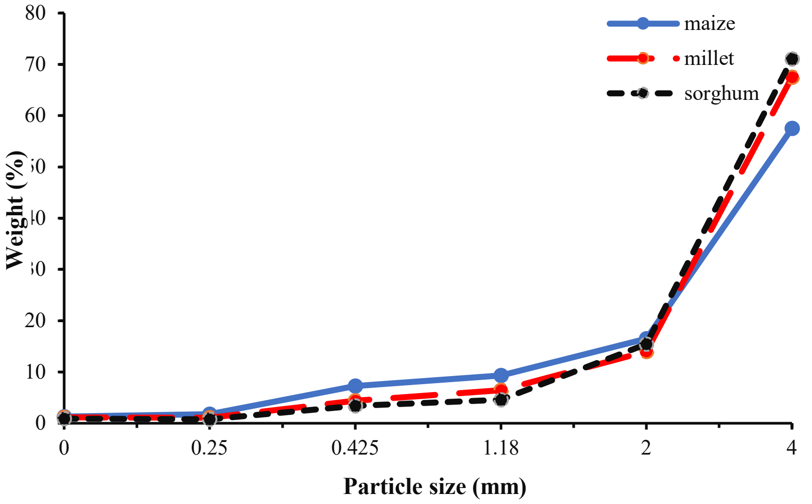

Figure 8 Particle size distribution of crop residues at the speed of 0.8 m s^{-1}

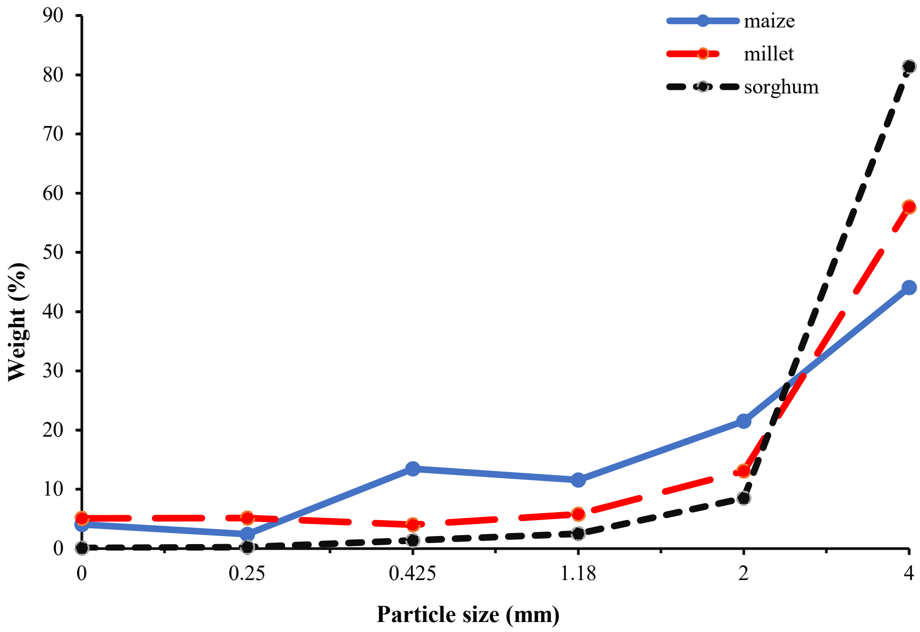

Figure 9 The particle size distribution of crop residues when processed at a speed of 1.6 m s^{-1}

4 Conclusion

A shredder for crop residues machine has been developed and its performance was evaluated using various crop residues like maize, millet, and sorghum stalks at three different rotational speeds. This shredder was made using locally available materials, equipment, and technology. The shredder achieved a maximum throughput capacity of 14.5 kg h^{-1} at a machine speed of 1.6 m s^{-1} with an overall efficiency being 82%. The data showed that the optimization of the shredding speed can lead to great reduction in the energy consumption used in crop residue shredding. There appears to be a trend of decreasing power consumption as the speed increased with maize going from 0.20 kWh at 0.4 m s^{-1} to 0.10 kWh at 1.6 m s^{-1} and millet from 0.25 kWh at 0.8 m s^{-1} to 0.10 kWh at 1.6 m s^{-1}. This shows that adjusting the shredding speeds to match crop properties can be an effective way to balance energy efficiency and processing effectiveness, which is valuable for sustainability.

The particle size distribution of maize, millet, and sorghum residues varied depending on the shredding speed. At a lowest speed of 0.4 m s^{-1}, the residues exhibit larger particle sizes, with sorghum retaining the highest proportion of 2-4 mm particles. These larger particles are beneficial for long-term soil health, as they decompose gradually and support microbial communities. As shredding speed increased to 0.8 m s^{-1}, the residues fell in a medium particle size range 2-0.425 mm, which could enhance microbial activity and increases the speed of composting when the residues are used for a purpose. This balanced distribution helps maintain soil structure and air channels in the compost. At the highest shredding speed 1.6 m s^{-1}, the residues, especially maize, trend towards smaller particle sizes produced fine particles which can decompose rapidly, releasing nutrients quickly but can momentarily immobilize nitrogen. The smaller particles are more suitable for short-term composting applications where faster decomposition is desired. Future studies could consider evaluating the performance of the machine using other crop residues and under wider machine speed ranges.

Acknowledgements: This research acknowledges the financial support provided by the Revenue Diversification pathways in Africa through biobased and circular agricultural innovations (DIVAGRI) funded by the European Commission Horizon 2020 under grant agreement number 101000348. It also received additional funding from the Sam and Emelia Brew Butler School of Graduate Studies/Graduate Student Association of Ghana grant, University of Cape Coast.

References

Abdulkadir, S. A., S. M. Dodo, B. G. Jahun, G. S. Malgwi, and I. Vanke. 2020. Design and construction of an agricultural waste shredding machine. *Arid Zone Journal of Engineering, Technology & Environment*, 16(3): 519–530.

Ahn, C. H., S. Lee, and Y. Park. 2024. Particle and bulk media characteristics of food waste compost-based biomedia by dynamic high-temperature aerobic composting process. *Environmental Technology & Innovation*, 35: 103711.

Al-Ogaili, A. S., A. Q. Al-Shetwi, H. M. Al-Masri, T. S. Babu, Y. Hoon, K. Alzaareer, and N. P. Babu. 2021. Review of the estimation methods of energy consumption for battery electric buses. *Energies*, 14(22): 7578.

Antwi-Agyei, P., J. Atta-Aidoo, L. Guodaar, and A. Dougill. 2023. Building climate resilience through crop residue utilization: Experiences of Ghanaian smallholder farmers. *Climate Resilience and Sustainability*, 2(4): e255.

Awgichew, A. 2020. Development and performance evaluation of power-driven chopper. *Asian Journal of Applied Science and Technology*, 04(04): 13–20.

Beniak, J., J. Ondruška, and V. Čačko. 2012. Design process of energy effective shredding machines for biomass treatment. *Acta Polytechnica*, 52(5):133-137.

Bergman, R. 2021. Drying and control of moisture content and dimensional changes. Chapter 13 in FPL-GTR-282. Washington, DC, USA: USDA Forest Service.

Busari, R., K. Alabi, R. Adebayo, and J. Dada. 2024. Rapid composting using a novel agricultural waste shredder. *FUOYE Journal of Engineering and Technology*, 9(1): 1–6.

Dattatraya Raut, P., and S. M. Bhalgat. 2020. Cutter blade design for shredder machine. *International Journal of Scientific and Research Publications (IJSRP)*, 10(06): 1022–1027.

Fan, S., and C. Rue. 2020. The role of smallholder farms in a changing world. In *The Role of Smallholder Farms in Food and Nutrition Security*, eds. S. G. Paloma, L. Riesgo, and K. Louhichi, ch. 2, 13–28. Cham: Springer International Publishing.

Gee, G. W., and D. Or. 2002. Particle-size analysis. In *Methods of Soil Analysis: Part 4 Physical Methods*, eds. J. H. Dane, and C. G. Topp, ch. 2.4, 255-293. Madison, WI, USA: Soil Science Society of America.

Jagadabhi, P. S., S. P. Wani, M. Kaushal, M. Patil, A. K. Vemula, and A. Rathore. 2019. Physico-chemical, microbial and phytotoxicity evaluation of composts from sorghum, finger millet and soybean straws. *International Journal of Recycling of Organic Waste in Agriculture*, 8(3): 279–293.

Jančík, F., P. Kubelková, R. Loučka, V. Jambor, D. Kumprechtová, P. Homolka, V. Koukolová, Y. Tyrolová, and A. Výborná. 2022. Shredlage processing affects the digestibility of maize silage. *Agronomy*, 12(5): 1164.

Jena, S., and R. Singh. 2022. Agricultural crop waste materials – A potential reservoir of molecules. *Environmental Research*, 206: 112284.

Khurmi, R. S., and J. K. Gupta, 2005. *A textbook of machine design*. New Delhi: Eurasia Publishing House.

Li, J., J. Liu, and B. Yang. 2013. Research on energy consumption of light metal scrap shredding process. *Journal of Mechanical Engineering*, 48(2): 71–77.

Li, L., X. Guo, T. Zhao, L. Liu, and T. Li. 2021. Identifying the key environmental factors and bacterial communities in humification and their relationships during green waste composting. *Applied Ecology and Environmental Research*, 19(1): 45-62.

Mathanker, S. K., T. E. Grift, and A. C. Hansen. 2015. Effect of blade oblique angle and cutting speed on cutting energy for energy cane stems. *Biosystems Engineering*, *133*, 64-70.

Nande, A., V. Chaudhari, S. Raut, and S. J. Dhoble. 2023. Management of agriculture waste materials: Challenges and future aspects. In *360-Degree Waste Management, Volume 1: Fundamentals, Agricultural and Domestic Waste, and Remediation*, eds. N. A. Raut, D. M. Kokare, B. A. Bhanvase, K. R. Randive, and S. J. Dhoble, ch. 2, 19–37. New York: Elsevier.

Patil, N. D. C., S. Kashyap, and S. Jarial. 2024. Agricultural waste management through crop residue management: challenges, solutions, and technological advancements. *In Exploring Waste Management in Sustainable Development Contexts*, eds. C. Mohan, S. Jeet, S. Dixit, and S. A. C. Carabineiro, ch. 12, 170-181. New York: IGI Global Scientific Publishing.

Pintens, D. A., K. J. Shinners, J. C. Friede, M. F. Digman, and K. F. Kalscheur. 2023. Impact—Shredding processing of whole-plant corn: machine performance, physical properties, and in situ ruminant digestion. *Agriculture*, 13(1): 160.

Pradhan, P., A. K. Sinha, and T. K. Pandit. 2024. The effect of stubble burning and residue management on soil properties: A review. *International Journal of Plant and Soil Science*, *36*(6), 36-49.

Ramulu, C., R. N. Pateriya, M. A. Naik, D. K. Vishwakarma, A. Kuriqi, N. Al-Ansari, A. Aataway, A. Z. Dewidar, and M. A. Mattar. 2023. A residue management machine for chopping paddy residues in combine harvested paddy field. *Scientific Reports*, 13(1): 5077.

Ruan, M., Y. Zhang, X. Wu, Y. Sun, Z. Huang, H. Li, A. Hu, Z. Wu, X. Zhang, X. Qin, and J. Huang. 2023. Effects of initial particle sizes of Triarrhena lutarioriparia on processing performance, material properties, and heavy metal speciation in sewage sludge composting. *Environmental Science and Pollution Research*, 30(8): 19980-19993.

Salo, V., S. Leshchenko, and D. Bohatyrov. 2021. The influence of the parameters of a chopping rotor for plant residues on the reliability of the technological process. *National Interagency Scientific and Technical Collection of Works. Design, Production and Exploitation of Agricultural Machines*, 51: 70–77.

Stegarescu, G., J. Escuer-Gatius, K. Soosaar, K. Kauer, T. Tõnutare, A. Astover, and E. Reintam. 2020. Effect of crop residue decomposition on soil aggregate stability. *Agriculture*, 10(11): 527.

Stetson, S. J., R. M. Lehman, and S. L. Osborne. 2018. Corn residue particle size affects soil surface properties. *Agriculture & Environmental Letters*, 3(1): 180004.

Udakwar, S., and D. Sarode. 2023. Production and characterization of pellets from agricultural residue: cotton, tur, and soybean. *Indian Journal of Production and Thermal Engineering*, 3(4): 1–10.

Waghmare, M., D. Nasane, J. Charpe, K. Kushwaha, R. Kose, S. Thawkar, and M. Giripunje. 2022. Development of solar powered shredder machine for waste management. *International Journal for Research in Applied Science & Engineering Technology*, 10(2): 305-310.

Yadvinder-Singh, H. S. Sidhu, M. L. Jat, N. Gupta, C. M. Parihar, and H. S. Jat. 2022. Crop residue management in conservation agriculture. In *Conservation Agriculture in India: A Paradigm Shift for Sustainable Production*, ed. A. R. Sharma, ch. 8, 158–178. London: Routledge.