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# Solar-Powered Biomass Shredder: A Sustainable Solution for Transforming Waste to Wealth

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## ABSTRACT

The present study, the biomass shredding technology powered by solar energy, presents an innovative approach to sustainable agricultural practices. A solar-powered biomass shredder offers an efficient and eco-friendly solution for processing agricultural waste into valuable resources. The shredder effectively processes diverse types of biomasses, including crop residues, branches, and organic waste, into smaller, manageable pieces. This shredder is suitable for dry crop residues having moisture content between 6-10%. This shredded biomass can be further utilized in several applications, such as organic composting, bio energy production, animal bed preparation, pellets and briquettes making, pot making and soil enrichment, etc. The process of shredding not only aids in waste management but also improves the decomposition rate and quality of compost, contributing to improved soil health and agricultural productivity. Additionally, the shredded biomass serves as an excellent feedstock for biogas plants, promoting renewable energy generation. The aim of this study was, to design a solar biomass shredder; the machine reduces reliance on fossil fuels, aligning with global efforts to promote green technologies, lowers greenhouse gas emissions and environmental stewardship.

**Key words:** Solar-powered, biomass shredder, sustainable solution, transforming waste to wealth

## INTRODUCTION

Agricultural production gives considerable amount of agriculture waste. Some of it recycle into the agriculture production as fertilizer while large amount remains unused and, in many instances, pose a disposal problem. A large portion of this crop waste is burnt in the fields across different parts of the state primarily to clear the leftover straw and stubbles after harvest (Singh, 2018; Anu *et al*., 2024). The unavailability of labour and the high logistic costs associated with waste removal and transportation are significant factors contributing to the preference for burning as the primary method of waste management (Kargwal *et al*., 2019; Singh and Ranguwal, 2022, Karawade *et al*., 2024; Pangalitan, 2024). Burning crop waste raises subsurface temperatures to around 33.8-42.2°C at a depth of 10 mm, with potential long-term effects potentially reaching up to 15 cm of topsoil. Regular burning destroys beneficial microflora and fauna, upsets the soil's carbon-nitrogen equilibrium and removes a significant amount of organic matter. Burning 1 tonne organic matter results in the loss of organic carbon, 5.5 kg of nitrogen, 2.3 kg of phosphorus, 25 kg of potassium and 1.2 kg of sulfur. Burning wheat straw reduces the bacterial population in the top 2.5 cm layer by 50% (Phalke *et al*., 2017). Dehydrogenase, fluorescein acetate (FDA) hydrolysis, β-Glucosidase, urease and acid and alkaline phosphatase levels of soil enzyme activity are reduced when crop waste is burned in fields. This decrease in microbial activity in the burned waste soil may disrupt nutrient cycling and soil productivity, ultimately affecting plant growth. Therefore, development of shredder provides a solution

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for agricultural residue management and harnessing renewable energy, thereby reducing global warming and carbon emission and promoting eco-friendliness (Xie and Jamaani, 2022; Liga *et al*., 2024). Developing efficient renewable energy-based systems has been in the spotlight of the scientists/researchers in order to overcome the environmental issues (Hashemian and Noorpoor, 2019; Hafidz *et al*., 2025).

Since the usage of a shredder is associated with huge power consumption requirements, the selection of suitable and appropriate shredding equipment becomes very crucial in biomass applications. Renewable energy sources are those resources that can be repeatedly harnessed to generate energy e.g. solar energy, wind energy, biomass energy, biomass and fuel cells, etc. The most abundant and easily available source of renewable energy is solar energy. Given the fact that almost 47% of the total energy emitted by the sun is intercepted by the earth, the scope for utilization of this plentifully available source of energy in remote locations of the countries that do not have a sufficient supply of electricity becomes immense.

The solar-powered biomass shredder supports a circular economy and sustainable development goals by converting agricultural waste into valuable products. This technology exemplifies a synergy between renewable energy and waste management, offering a practical solution for rural and agricultural communities aiming to enhance sustainability and economic viability.

## MATERIALS AND METHODS

The small lab cum pilot model of a solar biomass shredder was developed and evaluated at the College of Agricultural Engineering and Technology, CCSHAU, Hisar with the help of a local fabricator and a manufacturer from Maharashtra. The shredder consisted of a rectangular stainless-steel frame (SS 304) and had knife blades made of high carbon stainless steel. Solar panels were used to generate power. Detailed specifications of the machine are given in Fig. 1 (A, B and C). Solar biomass shredded was fed uniformly through the feeding hopper into the cutting unit. The rotation of the shaft was facilitated by pulleys and a motor, with plain knife blades attached to achieve biomass shredding through the shearing effect produced by the cutting blades. Then, the shredded biomass was passed through the holes of the sieve due to the centrifugal moment. Finally, the outer blade helped the shredded biomass come out from the shredder through the outlet.

Shredding efficiency was calculated using the following equation:

$$Es\,(\%) = \frac{\text{Total mass of biomass} - \text{Mass of unshredded biomass}}{\text{Total mass of biomass}} \times 100$$

Various parameters were considered in calculating the payback period and benefit-cost ratio of the solar biomass shredder. It was assumed there would be 300 solar days per year. Labour was assumed to work 7 hours per day at a rate of 300 Rs./day. The cost of raw materials was set at Rs. 2/kg, while the selling price was set at Rs. 5/kg. These assumptions were based on a survey conducted in farmers' fields and at the HAU farm.

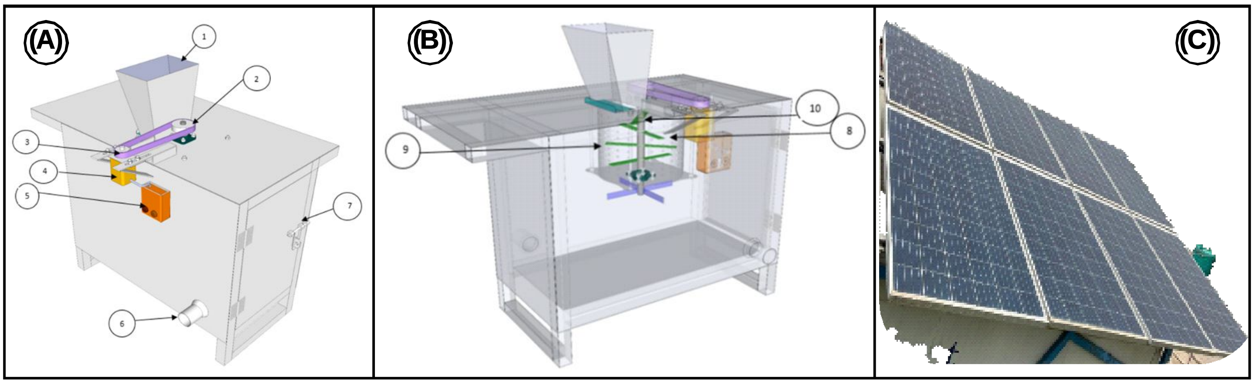


Fig. 1. (A, B) Solar biomass shredder showing different components (1) Feeding hopper, (2) Driven pulley, (3) Driver pulley, (4) Electric motor (5) Motor (6), Outlet (7), Door (8), Centralshaft (9), Cutting blades (10), Cylinder having round slots and (C) Solar panels.

These parameters were calculated using equation given below (Manjunatha, 2017; Anu *et al.*, 2024).

$$\text{Payback period} = \frac{\text{Initial investment (Rs.)}}{\text{Net annual profit (Rs./yr)}}$$

It is the ratio of annual benefit to the annual cost of the machine.

**Design Specifications and Calculation**

1. **Main frame:** The shredder consisted of a rectangular stainless-steel frame (SS304).
   Dimentions of the frame = 1010× 510×760
2. **Chopping unit:** Knife blades made of high carbon stainless steel,
   Cutter head (length × diameter), mm =300×326
   Number of blades and type = 4 Knife blades (45° angle of blade)
   Knife size in mm (length× height× thickness) = 270×60×4
3. **Feeding unit:** Feeding hopper (length× width×height), mm = 300×210×297
   Feeding opening (width x height), mm = 210×297
   Total number of sieve hole (Diameter of each hole) = 504 (12 mm)
4. **Power transmission system**
   Driven pulley diameter, mm = 90.0
   Driver pulley diameter, mm = 46.3
   Pulley ratio = 1:2
   Size of shaft (diameter), mm = 24.4
   Mechanism = Pulley with belt drive
   Life of machine = 8-12 years
5. **Prime mover:**
   Shredding process was done by the motor (Yaskawa AC motor).
   Electric motor capacity (Watt) = 750
   Rated rpm = 3000-6000
   Source of power = Solar power
   Inverter = 2.0 kW on grid solar inverter

**RESULTS AND DISCUSSION**

The independent factors such as moisture content (MC) and rotational speed (RPM), and their interaction significantly affected the shredding efficiency of shredder (Table 1). Maximum and minimum shredding efficiency of wheat straw was recorded 96.8% at 6% MC with 3500 RPM and 90.60% at 18% MC with 1500 RPM. Whereas in paddy straw maximum and minimum shredding efficiency was observed 97.60% at 6% MC with 3500 RPM and 86.2% at 14% MC with 1500 RPM (Table 2). This was observed because at the higher moisture levels, the wrapping of straw started to occur around cutting blades resulting in decreased shredding efficiency. The wrapping was more in the case of paddy straw. Whereas, in the case of increased RPM, shredding efficiency increased due to an increase in the number of cuts per unit time which resulted in the shredded straw of reduced length. According to literature, the cutting drum speed (1300, 1400, 1500 and 1600 RPM) and angle of knife edge (20°, 25°, 30° and 35°) affected the performance of the biomass shredder. The results revealed that the cutting efficiency of the rice straw increased with the increasing cutting drum speed, which was due to an increase in the number of cuts per unit of

**Table 1.** Coefficients from the predictive model equation for the responses of wheat straw and paddy straw

| Variables wheat straw | Shredding efficiency (%) for wheat straw | Variables paddy straw | Shredding efficiency (%) for paddy straw |
|---|---|---|---|
| Intercept | 95.10 | Intercept | 94.02 |
| $X_1$ | 0.4929*** | $X_1$ | 1.08* |
| $X_2$ | -2.97*** | $X_2$ | -4.04*** |
| $X_1 X_2$ | 0.0911 | $X_1 X_2$ | 0.4400 |
| $X_1^2$ | -0.0357 | $X_1^2$ | 0.2600 |
| $X_2^2$ | -0.8107*** | $X_2^2$ | -2.21** |
| Model (*F*- value) | 438.01*** | Model (*F*- value) | 37.84*** |
| $r^2$ | 0.9932 | $r^2$ | 0.9546 |
| Adjusted $r^2$ | 0.9909 | Adjusted $r^2$ | 0.9294 |
| Lack of Fit (p- value) | NS | Lack of Fit (p- value) | NS |

Where, $X_1$ = RPM, $X_2$ = Moisture content (%), Significant at 0.05< = P <0.1, **Significant at 0.01< = P <0.05; *** Significant at P <0.01 and NS–Non-significant (P-values are greater than 0.1).

**Table 2.** Experimental design (multilevel categoric methodology) for optimization of process parameters for wheat and paddy straw

| Run | Wheat straw | | | Rice straw | | |
|---|---|---|---|---|---|---|
| | Independent variables | | Responses | Independent variables | | Responses |
| | RPM | Moisture content (%) | Shredding efficiency (%) for | RPM | Moisture content (%) | Shredding efficiency (%) for |
| 1 | 2500 | 12 | 95.2 | 3500 | 14 | 89.2 |
| 2 | 1500 | 6 | 96.8 | 1500 | 6 | 95.7 |
| 3 | 3500 | 14 | 94.3 | 2500 | 10 | 93.4 |
| 4 | 1500 | 18 | 90.6 | 2500 | 8 | 95.4 |
| 5 | 2500 | 10 | 95.9 | 1500 | 12 | 91.7 |
| 6 | 3500 | 6 | 97.6 | 1500 | 14 | 86.2 |
| 7 | 1500 | 10 | 95.4 | 2500 | 12 | 92.4 |
| 8 | 1500 | 8 | 96.3 | 3500 | 10 | 94.7 |
| 9 | 2500 | 18 | 91.3 | 3500 | 6 | 97.6 |
| 10 | 2500 | 16 | 93 | 2500 | 6 | 96.4 |
| 11 | 3500 | 8 | 97.2 | 2500 | 14 | 87 |
| 12 | 1500 | 14 | 93.2 | 3500 | 12 | 94.3 |
| 13 | 3500 | 18 | 91.7 | 1500 | 8 | 94.3 |
| 14 | 1500 | 16 | 92.4 | 3500 | 8 | 96.3 |
| 15 | 1500 | 12 | 94.8 | 1500 | 10 | 92.6 |
| 16 | 2500 | 14 | 93.7 | - | - | - |
| 17 | 3500 | 16 | 93.6 | - | - | - |
| 18 | 3500 | 12 | 95.7 | - | - | - |
| 19 | 2500 | 6 | 97.3 | - | - | - |
| 20 | 2500 | 8 | 96.8 | - | - | - |
| 21 | 3500 | 10 | 96.3 | - | - | - |

time. The cutting efficiency increased from 58.5 to 86.4% with increasing cutting drum speed from 1300 to 1600 RPM at a 20-degree knife edge angle.

## Cost-economics Analysis of Solar Biomass Shredder

Fixed cost
Facility cost (machine + panel) = 300000 Rs.
Life of machine and panel = 20 years
Operating cost
Labour charges = 400 Rs./day
Raw material cost = 2 Rs./kg
Material's selling price = 5 Rs./kg
Solar days annually = 300 days
Annual fixed cost of machine/yr. (A) = 15000 Rs./year
Machine capacity = 40 kg/h
Operating time per day = 8 h
Labour charges @ Rs 300/day (B) = 120000 Rs. per year
Total crop residue requirement per year = 84000 kg
Electricity charges (C) = Nil
Total operating cost per year, A+B+C (D) = 135000 Rs.
Cost of crop residue @ Rs. 2/kg (E) = 192000 Rs. per year
Total cost of production (F = D+E) = 327000 Rs. per year
Selling price of crop residue @ Rs. 5/kg (G) = 432000 Rs. per year
Profit (F-G) per year = 105000 Rs.
Pay-back period = 2.86 year
B:C ratio = 7.00

The cost-benefit (BC) ratio and payback period of the solar biomass shredder were determined to be 7 and 2.86 years, respectively. The shredder's maximum power requirement was met by solar energy, with only a negligible amount of electricity used for initial start up. Thus, after 2.86 years, the user would begin to benefit from the machine for the remainder of its service life. The high BC ratio also indicated significant profit from the machine. The solar biomass shredders have significant potential to transform agricultural practices by integrating renewable energy with sustainable waste management. Their adoption can bring economic benefits to farmers, enhance environmental protection and contribute to global sustainability goals.

The burning of rice straw in field poses significant environmental pollution problems. One way to tackle this problem is to convert rice straw into the soil so that it may decompose *in situ* and the straw waste maybe converted to bio manures, however, for this purpose shredders are required to first job the rice straw into smaller pieces and then convert it to deeper soil layers with the help of mould board plough. Solar power shredder can help to solve this problem.

## CONCLUSION

This shredder is suitable for dry crop residues such as wheat and paddy straw having moisture content between 6-10% which can be used by farmers for setting up small business of providing shredded materials for briquetting/pelleting, vermicompost, biogas production, pot making, animal bedding, etc. This solar-powered biomass shredder supports a circular economy and sustainable development goals by converting agricultural waste into valuable products. This technology exemplifies a synergy between renewable energy and waste management, offering a practical solution for rural and agricultural communities aiming at enhancing sustainability and economic viability.

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