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Techno-Economic Feasibility Study of Tractor Pto Operated Shredder Cum Pulverizer

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

India's agricultural sector faces a challenge of widespread crop residue burning. An estimated 90-140 million tonnes of crop residues are burned annually by farmers across the country. The shredder cum pulverizer focuses on the shredding and pulverizing of coconut husks and fronds (*Cocos nucifera*), corn stalks (*Zea mays L.*) and subabul branches (*Leucaena leucocephala*). This shredded and pulverized crop residue is used to prepare the vermin compost, biomass production and various other purposes. The experiment was conducted at the IGKV, Raipur (C.G.). The detailed specifications parameters were optimized for each unit of the shredder cum pulverier. This study was conducted with four levels of feed rate varies with four levels of different speeds of operation at four moisture content) as the independent parameters. Their effects were studied on dependent parameters. The detailed data were analyzed statistically by SPD (Split Plot Design) with the three replications. The various performance parameters were also calculated. The result of the

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experiments showed that the shredding capacity and size of reduction of the shredder cum pulverizer with different feed rates of crop residues of coconut husks, coconut fronds, corn stalks, and subabul branches at different feed rates are 79.65 kg/h, 86.98 kg/h, 82.65 kg/h, and 94.64 kg/h, respectively, and the resultant size reductions of crop residues are 1.26mm, 2.66mm, 1.73mm, and 2.57mm, respectively. The result showed that the maximum shredding capacity 94.64kg/h was found on subabul branches were observed at 400kg/h feed rate, 40m/s speed of operation and 24% moisture content and the maximum size of reduction 1.26mm was found on coconut husks were observed at 600kg/h feed rate, 70m/s speed of operation and 24% moisture content. The cost of operation of shredder cum pulverizer was observed to be 983.25 Rs/h.

Keywords: Shredder cum pulverizer; crop residues; optimized; independent parameters; dependent parameters; shredding capacity; peripheral speed.

1. INTRODUCTION

India annually produces 71 million tonnes of crop residue, representing a fraction of the estimated 500-550 million tonnes generated globally. Despite this, a surplus of 140 million tonnes remains, of which a significant portion, 92 million tonnes, is burned each year. Chhattisgarh, a state known for its extensive maize cultivation, boasts 114,620 hectares of agricultural land dedicated to this crop, yielding an average of 1,692 kilograms per hectare.

It has been realized that large quantity of agricultural wastes remains being unutilized because handling, storage and management related difficulties. The reasons are their low bulk density, large area/volume for storage. The farmers on the field burn most of these wastes after the harvesting of crops. Thus the agricultural waste burning phenomena is being repeated every year. To harness the economic potential of agricultural waste, there is a pressing need for machinery that can effectively shred and process various types of residues, offering a practical and cost-effective solution [1].

The shredder machine is used for shredding i.e., converting macro agriculture waste and food waste into small easily decomposable forms, which can be used as organic manure. The different types of crop residues such as coconut husks, coconut fronds, corn stalks and subabul branches are used for evaluation of shredder cum pulverizer machine. The small-size waste will decompose faster than the large or macro-size waste. This decomposed waste can be used for the crops and this leads to improving the growth and quality of the crops and also improving the soil's chemical properties such as supply and retention of soil nutrients, and promotes chemical reactions. Approximately, burning of 98.4 Mt of crop residue has resulted in emission of nearly 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SO_x, 0.23 Mt of NO_x, 0.12 Mt of NH_3 and 1.46 Mt non-methane volatile organic compounds, 0.65 Mt of non methane hydrocarbons during 2008–2009, where CO_2 is 91.6% of the total emissions [2].

The coconut, a global agricultural powerhouse, holds the third position in worldwide production while leading in productivity. Corn, on the other hand, ranks seventh among global producers, contributing 2% to the total output. Subabul, a fast-growing legume tree, is cultivated extensively for various purposes, including biomass production. Shredding subabul branches is a vital step in processes such as biomass production, biofuel creation, composting, and animal feed preparation. The produced vermin-compost and biomass was rich in nitrogen, phosphorous, and potassium (NPK). The vermin-compost obtained had NPK compositions ranging from 0.3–4.19%, 0.21.6%, and 0.2–6.18%, respectively.

This paper presents the performance evaluation of tractor PTO operated shredder cum pulverizer machine using different crop residues such as coconut husks, coconut fronds, corn stalks and subabul branches.

2. MATERIALS AND METHODS

The performance evaluation of tractor PTO operated shredder cum pulverizer machine was evaluated in Swami Vivekananda College of Agricultural engineering & Technology and Research Station, Faculty of Agricultural Engineering, IGKV, Raipur during the year 2023-2024. The different types of crop residues (coconut husks, coconut fronds, corn stalks and subabul branches) were used for testing of shredder cum pulverizer machine with independent parameters like PTO torque, speed of operation, feed rate, and moisture content were studied on two dependent parameters shredding capacity and size reduction. The cost of operation, breakeven point and payback period was also calculated to evaluate the performance of the shredder cum pulverizer machine.

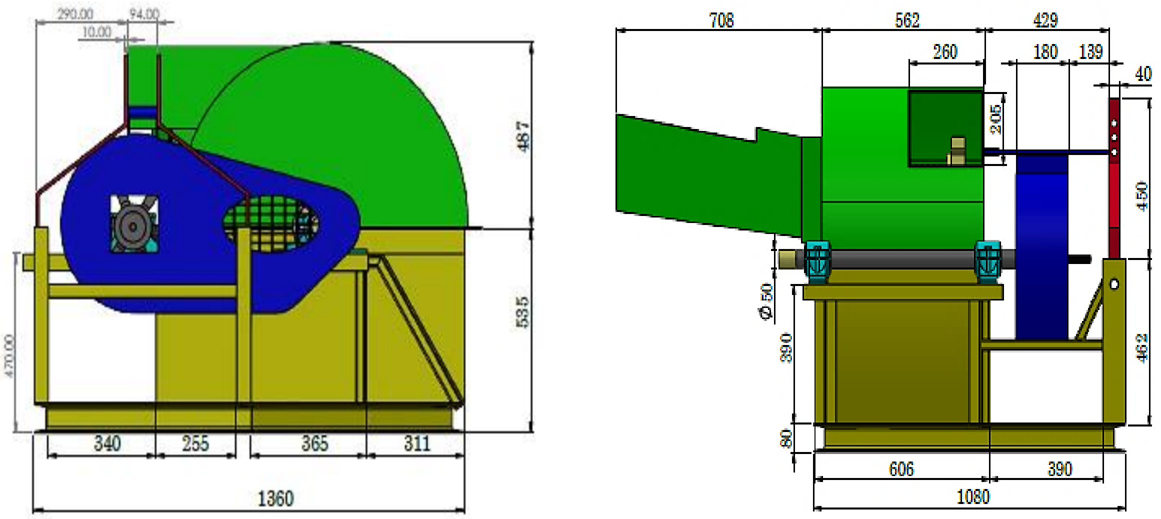
2.1 Specifications and working principle of Shredder cum Pulverizer

The shredder consisted of rectangular stainless steel frame which is made up of mild steel and had blades made of mild steel. The shredder cum pulverizer has been designed for chopping and pulverizing the crop residues into small pieces suitable for animal fodder and the preparation of vermicompost. The shredder cum pulverizer consists of a circular drum in which the shredder and pulverizer blades are mounted. The shredder is operated by a tractor PTO, and power is transmitted from the bigger pulley to the smaller pulley through the shaft via the pulley’s v-belt. It is manually fed with residues one at a time through the feeding chute. The whole residue passes horizontally into the rotating drum, and then it goes to the shredder blade, where it is chopped into pieces and then chopped into small pieces through the pulverizer at different sizes ranging from 7 to 9 mm. The overall shredder cum pulverizer was 1360 mm in length, 1699 mm in width, and 1022 mm in height. The weight of the shredder cum pulverizer is 650 kg. The specification and CAD design of tractor PTO operated shredder cum pulverizer machine shown in Table 1 and Fig. 1 respectively.

Table 1. Detailed specifications of shredder cum pulverizer

S. No.	Parameters	Specifications
1.	Make	Gomathi
2.	Model	GSP 45 S 60
3.	Type	Tractor PTO operated shredder cum pulverizer/coconut frond chopper
4.	Hitching/Attachment	CAT-II 3 point linkage
5.	Shape of the frame	Rectangular
6.	Machine length (mm)	1360
7.	Machine width (mm)	1699
8.	Machine height (mm)	1022
9.	Tractor power (hp)	45 hp and above
10.	Output(kg per hour)	3800 to 4500
11.	Weight(kg)	650
12.	Drum diameter (mm)	790
13.	No. of shredder blade	
	Movable	6 no's
	Fixed	1no’s
14.	Size of shredder blade	
	Length (mm)	380
	Width (mm)	50
	Thickness (mm)	30
15.	No. of pulverizer blade	60
16.	Size of pulverizer blade	
	Length (mm)	175
	Width (mm)	50
	Thickness (mm)	10
17.	PTO input speed(rpm)	540 (max)
18.	Transmission Drive	Belt
19.	No. of belt	3 no's
20.	Type of belt	V- belt
21.	Axle	
	Diameter(mm)	400
	Length (mm)	790
22.	Feeding Chute	
	Length (mm)	710
	Width (mm)	464

S. No.	Parameters	Specifications
	Thickness (mm)	350
23.	Discharge chute	
	Length (mm)	143
	Width (mm)	260
	Thickness (mm)	205
24.	Cutting disc Thickness (mm)	22
25.	Recommended Output(rpm)	1920(max)



Back view of shredder cum pulverizer model **Side view of shredder cum pulverizer**

Fig. 1. CAD design of tractor PTO operated shredder cum pulverizer machine

Fig. 2. Testing of tractor PTO operated shredder cum pulverizer

Table 2. Different independent and dependent parameters for the study on design parameters for the shredder cum pulverizer

S. No.	Parameters	Variables	Levels
1.	Independent variables	1. Speed of operation (m/s)	4
		2. Feed rate (kg/h)	4
		3. Moisture content (%)	4
2.	Dependent variables/ actual variables	4. Shredding capacity(kg/h)	
		5. Size reduction (mm)	

2.2 Calculation of Dependent Parameters

The performance of the machine is influenced by the dependent parameters of PTO torque, operating speed, feed rate, and moisture content. These parameters are determined by the formula provided below.

2.2.1 Shredding Capacity

Shredding capacity can be computed using the Equation 1 [3].

$$\mathrm{Sc} = \frac{\text{Mass of shredded crop residues (kg)}}{\text{Time Taken (h)}} \quad -(1)$$

Where,
Sc = Shredding capacity

2.2.2 Size reduction

It is useful to know the shredded size of the residues initially the size of the crop residues can be measured using measuring tape and vernier callipper and after operation we use gyratory sieve shaker to know the difference in their sizes and to know the size reduction of the shredder. The degree of pulverization was measured by determining the Mean Weight Diameter (MWD) of crop residues after performance evaluation by using sieve analysis technique. For this, sieves of appropriate mesh sizes were selected to assess the degree of pulverization. A set of 7 different sizes (4.2, 1.18, 0850, 0.71, 0.500, 0.10mm) were used with size decreasing downwards up to the pan. The sieve set consisted of sieve sizes according to ISS standards 460-1962. The sieve analysis was done by using gyratory sieve shaker. The weight mean of the crop residues in different sieves was found. The weight of residues retained by each sieve was also noted down. The mean weight diameter of crop residues was calculated by using Equation 2 [4].

$$\mathrm{MWD} = \frac{(\sum \mathrm{W}_{\mathrm{i} \times \mathrm{d_i}})}{\mathrm{W_T}} \quad ---(2)$$

Where,
MWD = Mean weight diameter, mm
d_i = average diameter of i and $(i+1)^{th}$ sieve in gm, $d_i < d_i + 1$
W_i = weight of residues retained on the i^{th} sieve in gm
W_t = total weight of soil sample in gm

3. RESULTS AND DISCUSSIONS

An experiment was conducted to optimize the different design parameters. The effects of these parameters were discussed under following subsection.

3.1 Effect of Feed Rate, Speed of Operation and Moisture Content on Shredding Capacity for Coconut Husks

The interactive effect of feed rate, speed, and moisture content on shredding capacity was found to be significant at the 5% level of significance. An increase in feed rate provides more material for the shredder to process, thereby enhancing shredding capacity. Similarly, higher drum speeds result in faster blade rotation, allowing more material to be processed in a given time, which also boosts shredding capacity shown in Fig 2. However, higher moisture content in coconut husks, which makes the material softer and more pliable, negatively impacts the efficiency of shredding. The wet material tends to clog the machine and stick together, making it difficult for the blades to cut and process efficiently, thus reducing the shredding capacity. Consequently, while higher feed rates and speeds generally increase shredding capacity, increased moisture content diminishes it. The highest shredding capacity was observed at a feed rate of 79.65 kg/h, a speed of 70 m/s, and 16% moisture content, whereas the lowest capacity was recorded at 60.077 kg/h, a speed of 40 m/s, and 24% moisture content. Feed rate was significantly influenced by both the speed of operation and the moisture content. The similar findings were also reported by Kumar et al. [5] and Syed et al. (2020) for coconut husks.

3.1.1 Effect of feed rate, speed of operation and moisture content on Size reduction for coconut husks

Size reduction is significantly influenced by feed rate, speed of operation, and moisture content at the 5% level of significance. The analysis showed that most fronds were retained in the first, second, and third sieves, with the size of shredded coconut husks on the sieves increasing linearly with higher feed rates and speeds of operation. However, the size of crop residues decreased with increased speed and moisture content. A higher feed rate typically results in greater size reduction due to increased interaction between the material and the cutting drum. Similarly, higher speeds facilitate size reduction by providing more energy for the cutting tool to break down the material. Moisture content is also critical; wetter materials are easier to break down as moisture acts as a lubricant, reducing friction. The study found that increasing feed rate or speed of operation led to larger coconut husk particles being retained on sieves due to the increased force, resulting in less breakage. Conversely, increased speed or moisture content produced smaller particle sizes due to enhanced cutting action and increased material flexibility. Similar findings were reported by Elsaied et al. [6] for coconut husks. The maximum size reduction observed was 1.26 mm at a 600 kg/h feed rate, 70 m/s speed, and 24% moisture content, while the minimum size reduction was 7.93 mm at a 400 kg/h feed rate, 40 m/s speed, and 24% moisture content.

3.2 Effect of Feed Rate, Speed of Operation and Moisture Content on Shredding Capacity for Coconut Fronds

The difference in feed rate was found to be significant at the 5% level of significance, with minimum differences required for statistical significance indicated by the critical differences and standard errors provided. Generally, increasing the feed rate boosts shredding capacity, but excessive feed rate can overload the shredder, reducing efficiency, increasing power consumption, and potentially causing machine damage. Similarly, increasing the speed of operation typically enhances shredding capacity, though there is an optimal speed beyond which further increases may not yield significant gains and could lead to higher energy consumption and wear shown in Fig. 3. Coconut fronds with low moisture content, while easily shredded due to their brittleness, can produce dust and accelerate wear on the shredder. High moisture content, on the other hand, can clog the shredder, reduce efficiency, and increase power consumption. Optimal shredding capacity and efficiency are typically achieved within a specific moisture content range. As feed rate increases, shredding capacity tends to rise with higher speeds and lower moisture content in crop residues. Similar findings were reported by Elsaied et al. [6] for coconut fronds. The maximum shredding capacity was observed at a feed rate of 88.31 kg/h, 70 m/s speed, and 16% moisture content, while the minimum shredding capacity was 61.65 kg/h at 40 m/s speed and 24% moisture content. Feed rate was significantly influenced by speed of operation and moisture content.

3.2.1 Effect of feed rate, speed of operation and moisture content on Size reduction for coconut fronds

Size reduction is significantly influenced by feed rate, speed of operation, and moisture content at a 5% level of significance, with a notable interaction among these parameters indicating that their combined optimization yields the best results. Higher feed rates generally lead to increased size reduction due to more collisions and breakage, although extremely high rates may overload the machine, reducing efficiency. Similarly, increasing the speed of operation tends to enhance size reduction by generating more forceful impacts, but there is likely an optimal speed beyond which the benefits may diminish. In contrast, higher moisture content usually reduces size reduction as wet materials are more pliable and less likely to break into smaller particles. The maximum size reduction of 2.66mm was observed at a feed rate of 700 kg/h, an operating speed of 60 m/s, and a moisture content of 16%, while the minimum size reduction of 9.98mm occurred at a feed rate of 500 kg/h, a speed of 70 m/s, and a moisture content of 24%.

3.3 Effect of Feed Rate, Speed of Operation and Moisture Content of Shredding Capacity for Corn Stalks

The difference in feed rate was found to be significant at the 5% level of significance, with a difference considered statistically significant if it exceeds the critical difference between any two means. As the feed rate increases from 300 kg/h to 600 kg/h, the shredding capacity generally increases due to the higher volume of material being processed. However, excessive feed can overload the shredder, reducing capacity. Similarly, increasing the speed of operation from 40 m/s to 70 m/s typically enhances shredding capacity, as faster blade rotation allows quicker cutting of corn stalks. Yet, overly high speeds may reduce capacity by preventing proper shredding. The effect of moisture content on shredding capacity is more nuanced as shown in Fig. 4 lower moisture content (around 12%) tends to increase capacity as drier, more brittle corn stalks are easier to shred. However, when moisture content drops too low (to around 24%), shredding capacity may decrease due to the creation of dust and handling difficulties. The maximum shredding capacity observed was 82.65 kg/h at a feed rate of 70 m/s and 16% moisture content, while the minimum was 60.38 kg/h at 40 m/s speed and 16% moisture content. The feed rate was significantly influenced by both speed of operation and moisture content.

3.3.1 Effect of feed rate, speed of operation and moisture content on Size reduction for corn stalks

Size reduction is significantly influenced by feed rate, speed of operation, and moisture content at a 5% level of significance. Higher feed rates 600 kg/h typically result in greater size reductions compared to lower feed rates 300 kg/h, while increased speeds of operation 24 m/s tend to produce smaller size reductions compared to lower speeds 12 m/s. Moreover, higher moisture content 70% leads to larger size reductions compared to lower moisture content 40%. An increase in feed rate generally results in larger particle sizes due to machine overload, while a decrease allows finer grinding. Higher operation speeds yield smaller particles due to increased force, whereas lower speeds result in larger particles due to reduced impact. Increased moisture content produces larger particles due to the difficulty in breaking down wet corn stalks, whereas decreased moisture content, although yielding finer particles, may also cause dust and equipment damage. The highest mean weight diameter was recorded in the first sieve, with a maximum value of 1.73 mm at a 400 kg/h feed rate and 60 m/s speed of operation at 16% moisture content, while the minimum value was 8.98 mm at a 600 kg/h feed rate and 70 m/s speed of operation at 24% moisture content. The feed rate was significantly affected by both speed of operation and moisture content, consistent with findings reported by Lomchangkum et al. [7].

3.4 Effect of Feed Rate, Speed of Operation and Moisture Content on Shredding Capacity for Subabul Branches

The shredding capacity of subabul branches varies with different feed rates (200, 300, 400, and 500 kg/h), speeds of operation, and moisture contents (12%, 16%, 20%, and 24%). Generally, higher feed rates lead to increased shredding capacity, though the effects of moisture content and speed of operation are more complex. While increasing the feed rate boosts shredding capacity by processing more material per unit time, exceeding the shredder's capacity can result in overloading, reduced efficiency, and potential equipment damage. A balanced speed of operation can improve particle size uniformity, but excessive speed may reduce particle size, increase energy consumption, and accelerate wear on shredder components. Higher moisture content can enhance shredding capacity by making the material more pliable, though too much moisture can clog the shredder and reduce efficiency. Conversely, lower moisture content may reduce shredding capacity as dry material is harder to cut and can cause more wear on the equipment [8,9]. The highest shredding capacity observed was 94.64 kg/h at a speed of 70 m/s and 16% moisture content, while the lowest was 63.72 kg/h at 40 m/s and 24% moisture content. The feed rate was significantly influenced by both speed of operation and moisture content.

3.4.1 Effect of Feed Rate, Speed of Operation and Moisture Content on Size Reduction for Subabul Branches

Size reduction in subabul branches is significantly influenced by feed rate, speed of operation and moisture content at a 5% level of significance, with a notable interaction among these factors indicating that their combined optimization yields the best results. The size reduction increases linearly with higher feed rates, especially at increased operational speeds, and is more pronounced when moisture content is high. Overloading the shredder with too high a feed rate can cause inefficiencies, leading to uneven shredding, while higher speeds improve size reduction but also increase the mechanical load, risking faster wear and overheating. Moist stems, due to higher moisture content, are easier to shred, producing finer particles, although excessive moisture may cause clogging. Achieving optimal size reduction, therefore, requires carefully balancing feed rate, speed, and moisture content to maximize efficiency while avoiding overloading and excessive wear. The analysis revealed that most stalks were collected in the first three sieves, with a mean weight diameter of 2.57 mm at 60 m/s and 24% moisture content, while the smallest was 8.98 mm at 70 m/s and 12% moisture content [10].

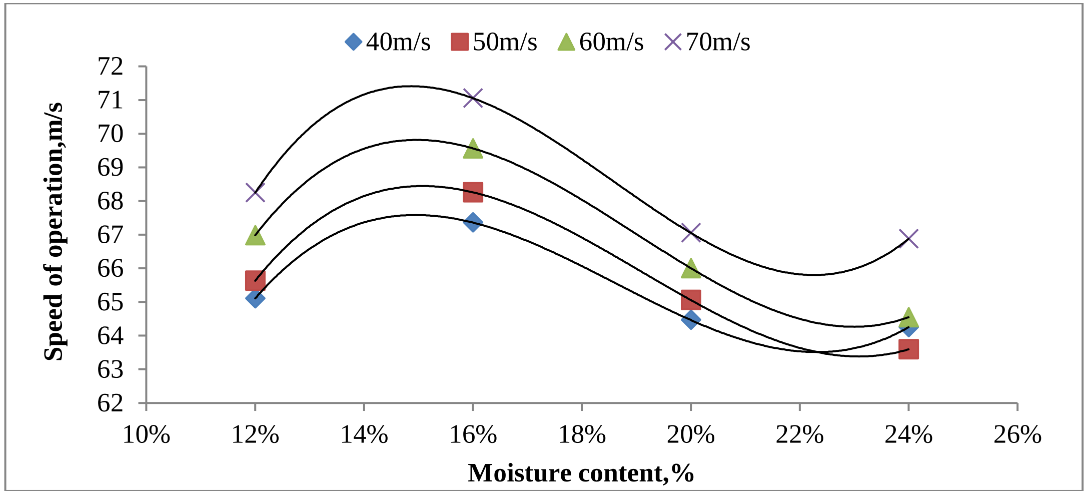


Fig. 3. Effect of speed of operation and moisture content on shredding capacity of coconut husks

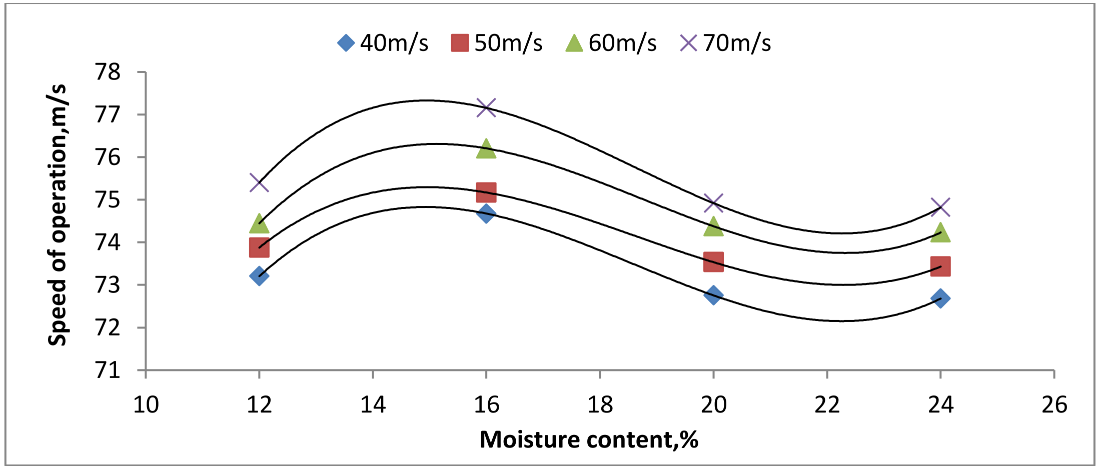


Fig. 4. Effect on Speed of operation and Moisture content on shredding capacity for coconut fronds

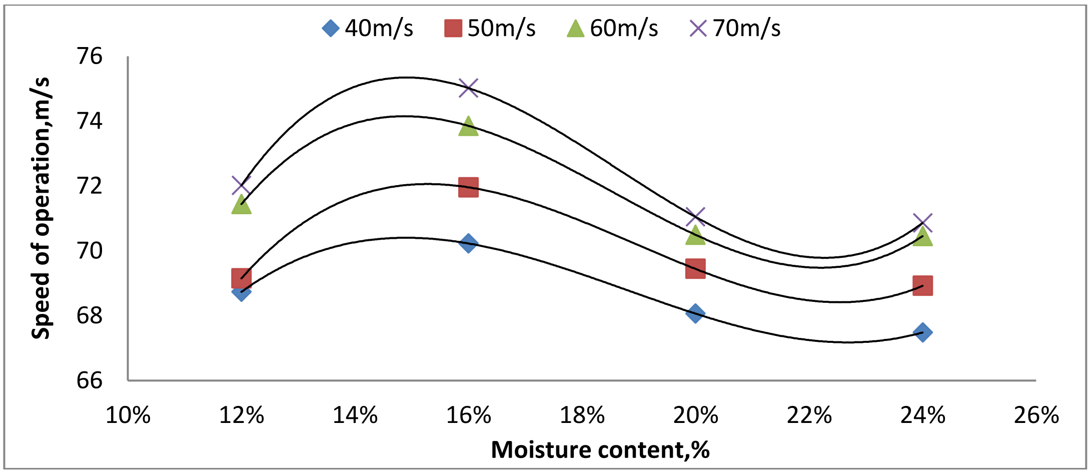


Fig. 5. Effect of Speed of operation and Moisture content on shredding capacity for corn stalks

Table 3. Performance evaluation of tractor PTO operated shredder cum pulverizer

S. No.	Crop residues	Parameters	
		Shredding capacity, kg/h	Size reduction, mm
1	Coconut husks	79.65	1.26
2	Coconut fronds	88.31	2.66
3	Corn stalks	82.65	1.73
4	Subabul branches	94.64	2.65

4. CONCLUSION

Performance evaluation of tractor PTO-operated shredder cum pulverizer shows that t the maximum shredding capacity of subabul branches was found to be 94.64 kg/h and maximum size of reduction of 1.26 mm was found on coconut husks. The machine is user-friendly and adaptable to various types of crop residues. The result shows that the shredding capacity increases with increasing feed rate and speed of operation and decreases with decreasing moisture content. Also the size reduction of different crop residues increases with the increase in speed of reduction and moisture content. The cost of operation of tractor PTO operated shredder was obtained to be 982.37Rs/h. The shredder cum pulverizer reached its breakeven point after 150.49 hours of operation. The payback period for the machine was calculated to be 2.28 years.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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