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Design and Development of a Solar Energy-Powered Sugarcane Detrasher

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ABSTRACT

This research article focuses on the design and development of a solar energy-powered sugarcane detrasher to improve the efficiency of sugarcane harvesting and reduce manual labor. Sugarcane is a globally significant crop, and its manual harvesting involves labor-intensive tasks such as removing dry and green trash from the harvested stalks. While various mechanical detrashers have been developed, many of them rely on fossil fuels, which can be problematic due to their environmental impact and limited availability. To address this issue, the researchers designed and built a solar energy-powered detrasher to enhance the efficiency of sugarcane detrashing while promoting the use of renewable energy. The developed detrasher consists of a solar panel, a battery, a DC motor, and a pair of counter-rotating rollers with detrashing rubber. The rollers grip the sugarcane stalks and remove the trash through friction. The solar panel provides power to the DC motor, allowing the detrasher to function efficiently. The study also includes a detailed analysis of the power requirements for detrashing, the selection of solar photovoltaic components, and the performance evaluation of the developed system. Results indicate that the solar-powered sugarcane detrasher achieved substantial detrashing efficiency, ranging from 70.8% to 84.91%, and an output rate of 0.67 to 0.89 tons per hour. The developed system demonstrated its capability to enhance efficiency, reduce labor, and decrease operational costs compared to traditional manual methods.

1. Introduction

Sugarcane (Saccharum officinarum) is a vegetatively cultivated crop that is planted in over 80 countries and yields 11.8 million tonnes of sugar. The yearly global sugarcane production is approximately 1794 million tonnes, with a cultivation area of 25.4 million hectares. Sugarcane accounts for 70% of global sugar production. India is the world's leading consumer of sugar and the second-largest producer of sugarcane after Brazil. The total sugarcane production is about 357 million tonnes with a productivity of 68 tonnes per hectare from the cultivation area of 5.08 million hectares (Kishore et al., 2017). Harvesting of sugarcane involves base cutting of standing cane stalks, topping of green tops, removal of dry trash, and collecting of cleaned cane stalks. In India, harvesting of sugarcane is done manually which is a time-consuming, arduous operation, and requires more labor at peak time of harvesting season. According to Shukla et al., (1991), the labor requirements for manual cutting and cleaning (removal of tops, dry, and green leaves) of sugarcane were 157 and 395 man-h/ha, respectively. In India, manual tools were used to remove garbage from harvesting cane, which took around 70% of the work. Farmers are still using manual methods to remove the trash because of the non-availability of suitable machinery for detrashing the cane. Some of the hand tools were commercialized and those were developed in the IISR, TNAU, and OUAT institutes for the detrashing operation. However, due to human drudgery, these tools cannot be used for an extended period. Srivastava and Singh (1990) designed and developed a tractor-powered sugarcane detrasher to remove both green and dry trash from

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harvested sugarcane. It had a cane feeding beater, a cane take-off beater, two rollers, a lower, and a feeding trough. The efficiency of detrashing was reported to be dependent on the peripheral speed of the detrashing rollers. Bastian and Shridar (2014) reported that the de-trashing efficiency increases with the de-trasher roller speed and the optimum arrived is 13.75 m/s with a spiral angle of zero degrees. Mechanization can also increase the total energy efficiency of sugarcane-based farming by reducing labor scarcity and ensuring timely sugarcane harvesting operations. Singh and Solomon (2014) evaluated a tractor PTO-operated sugarcane detrasher. It consisted of a pair of counter-rotating detrashing rollers. Depending on the type, the proportion of trash that remained in the detrashed cane after going through the detrasher ranged from 1.5 to 6.6%. The garbage removal efficiency and detrasher output ranged from 77.5 to 94.5% and 2.4 tonne/h, respectively. When compared to the previous method, the developed detrasher saved 17% and 84% in operation costs and manpower requirements, respectively. The process of manual harvesting involves the selection and collection of sugarcane stalks, followed by the removal of their leaves and individual breaking of the tops. This can be achieved through either manual labour or the use of manual equipment. Even though manual harvesting exhibits a comparatively low contamination rate and yields high-quality harvests, it is characterized by its labor-intensive nature, high costs, and inefficiency. Based on statistical data, it has been observed that the manual technique employed for the separation of sugarcane leaf stalks contributes to approximately 60% of the overall manual harvesting duration (Ashfaq, 2014). The refined TNAU detrasher resulted in 13.0 percent and 14.5 percent saving in cost and time, respectively, when compared to conventional hand detrashing (Kathirvel et al.,2010). When compared to the traditional method of direct hand-stripping, the hand tools developed by the Indian Institute of Sugarcane Research (IISR) and Tamil Nadu Agricultural University in India show a moderate gain in efficiency ranging from 6.2% to 11.4%. According to Singh and Solomon (2014), mechanical methods of stripping demonstrate a minimum efficiency improvement of 84% compared to the manual method. Consequently, various major sugarcane-producing nations have been actively working on the development of mechanical harvesting techniques to enhance labour productivity (Santoro, 2017).

It was concluded from the review that some of the researchers have developed sugarcane detrasher but these detrashers were operated with fossil fuel (diesel or petrol). The biggest challenges to mechanized agriculture in rural areas are faster fossil fuel depletion, rising prices, and a lack of fossil fuel availability. Hence, these engine-powered detrashers are not well-liked by farmers in rural areas. Furthermore, mechanization at the expense of pollution is unacceptably high. As a result, to satisfy rising energy demand, the Government of India (GOI) began pushing for the use of renewable resources (Anonymous, 2018), which requires efforts to be made to utilize solar energy for cane harvesting in rural regions. Solar energy is utilized in agriculture in India for postharvest operations such as drying food grain, cooking, desalinizing water, water pumping, and so on. Some solar photovoltaic agricultural apparatus, such as pumps, seeders, and grass cutters, were also designed to boost power input in the farm area. Because the solar intensity was not constant during the operational hours, all of the reported solar energy-powered machinery used solar photovoltaic systems with storage backups to power the gear. (Chaurey et al., 1993; Swetha and Shreeharsha, 2015; Amrutesh et al., 2014). But so far no literature has been reported related to the development of a solar energy-operated sugarcane detrasher. India is a tropical country, the solar radiation is receivable in ampleness for living people. Therefore, keeping in mind operation cost, timeliness of operation, labor saving, and human drudgery, a solar energy-powered whole stalk sugarcane detrasher was designed and developed to increase the use of renewable energy.

2. Material and methods

Geographical location and climatic condition

The longitude and latitude of the geographical location of the experimental test site were 17.0894° N and 82.0668° E, respectively from the mean sea level. The climatic condition of the test was observed to be humid temperate.

Development of Solar Energy Powered Sugarcane Detrasher (SPSD)

A prototype of a solar energy-operated cane detrasher was developed as shown in Fig 1. It consisted of a solar panel, battery, DC motor, a pair of counter-rotating rollers, and detrashing rubber. The function of output rollers was to grip the cane stalks and push them forward. Considering the maximum diameter of the cane, the clearance between the rollers was kept at 20 mm to pass the cane forward without causing any physical harm to it. The surface of each roller was covered with a rubber belt to provide a better grip between the cane and the belt. A 350 W, 24 V DC motor was used to rotate the lower roller whereas the upper roller was connected through the belt and pulley. The position of the upper roller was kept adjustable to accommodate canes of various sizes. The effective diameter of both the rollers was 100 mm. Detrashing rubber was used to remove the dry and green leaves of cane stalks due to the friction. The power flow diagram of the solar-powered sugarcane detrasher is given in Fig. 2.

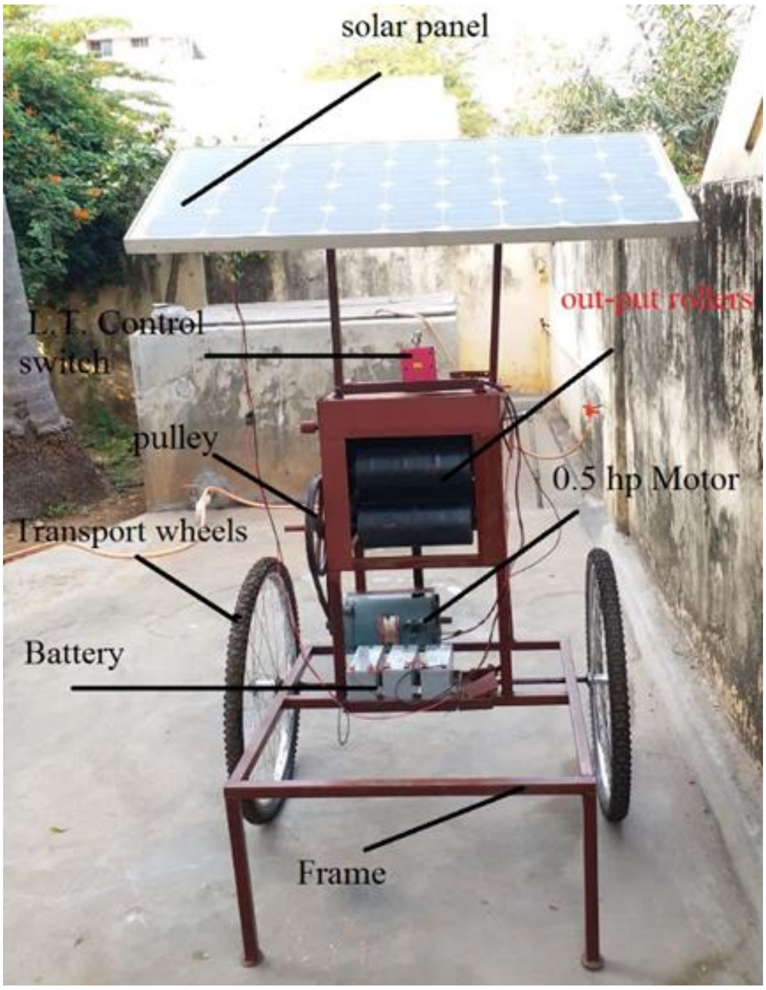

Figure 1. Back side view of the developed solar energy-powered sugarcane detrasher

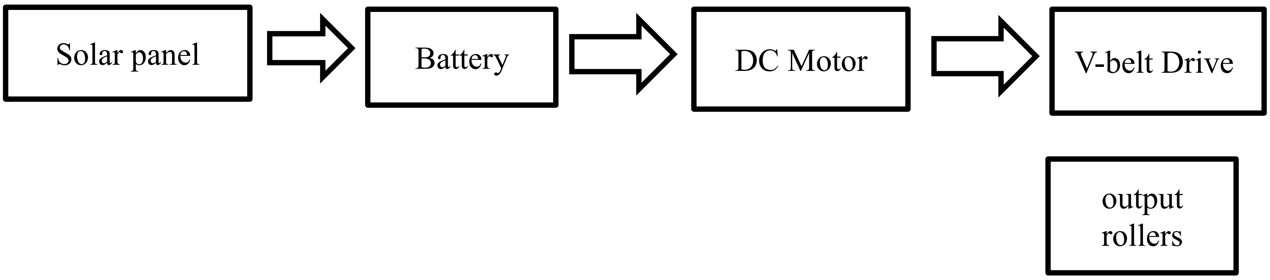

Figure 2. Power flow diagram of proposed solar-powered sugarcane detrasher

Design of Solar Photovoltaic (PV) system for sugarcane detrasher

Solar PV systems mainly comprise four components a) solar panel for receiving the solar radiation; b) Battery for the storage of charge; c) DC motor for running the detrasher

Estimation of power requirement for carrying out detrashing

The power required for detrashing sugarcane was estimated in consideration of its physical properties like variety, the thickness of the trash over the cane, the diameter of the cane, and the rotating speed of the output rollers.

The total power required for detrashing the cane was calculated using Equation (1).

$$P_T = (P_1) + (P_2) \qquad \text{....(1)}$$

Power required by the output roller (P_1) was calculated using Equation (2).

$$P_1 = \text{Frictional force } (F_f) \times \text{velocity of output rollers(V)} \qquad \text{....(2)}$$

The frictional force between cane stalks and rollers was the product of the weight of the cane (average mass of cane 900

g) and the coefficient of friction between cane and rollers (μ = 0.6)

The frictional force was calculated as 5.4 N. The Velocity of the output roller was calculated as 2.94 m/s by taking the roller diameter and rotational speed as 100 mm and 562 rpm, respectively.

Power required by the cutter for removing the green top (P_2) was calculated using Equation (3).

P_2 =Shear force (τ)×velocity (v_1) ….(3)

By taking the cutting area 35 mm^2, the Shear force was calculated as 35 N (Ashraf., 2016), and the velocity of removing the green top was determined as 7.44 m/s (considering 948 rpm and 0.15 m diameter of the cutter). The power required for the green top cutter was found to be 260.44 W. Total power required for detrashing cane was calculated as 315 W (taking a 20% factor of safety).

Selection of solar photovoltaic panel

The size of the solar panel was selected using Equation (4). $\text{Total power of PV panel} = \frac{\text{Total power consumption}}{\text{Efficiency of battery}}$ ….(4)

The size of the panel was obtained as 375 W (since the efficiency of the battery is 80%)

Due to the bigger size and high cost of solar panels, a 75 W solar panel (18.25 V, 4.5 amp) was used. However, to compensate for the size of the panel, the time of charging of battery was increased.

Selection of battery

One 75 W solar panel was used to recharge the battery and simultaneously supplied power to run the DC motor. The capacity of the battery was calculated following Sahu and Raheman, (2020).

$$\text{Battery capacity} = \frac{(\text{Total Watthours per day used by appliances} \times \text{Days of autonomy})}{(\text{discharge rate of battery} \times \text{nominal battery voltage})}$$

….(5)

By assuming a nominal voltage of 24 V and one hour of use each day, the capacity of the battery was estimated to be 15.62 Ah. To achieve the required range of voltage and current, four 12 V and 7 amp batteries were used, two of which were connected in series and two of which were connected in parallel.

3. Results and discussion

The performance evaluation of the developed SPSD was evaluated with freshly harvested sugarcane (variety CO 1148). The weight of the cane before and after detrashing and the trash left was measured using a weighing balance as shown in Figure 3 (a, b, and c).

Prediction of the monthly average of daily global radiation at Kakinada

The total amount of solar energy falling on a horizontal surface is known as global solar exposure. The total solar energy for a day is defined as daily global sun exposure. Theoretical values of daily global radiation were calculated and its variations throughout the year are shown in Fig 4. The daily global radiation throughout the year for Kakinada varied from 4000 to 6000 W/m^2 for a single day. Daily global radiation per hour was measured and it was found to be 700 W/m^2 on 30th March 2019 at 11:00 AM.

(a) (b) (c)

Figure 3. Measurement of the weight of sugarcane before and after detrashing and trash left

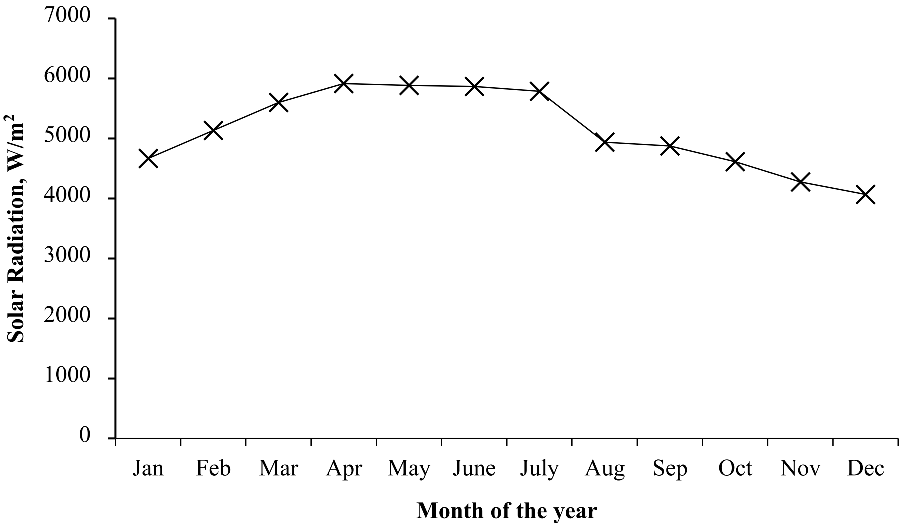

Figure 4. Average solar radiation available at Kakinada (India)

Conversion Efficiency of a 75 W Solar Panel

A solar panel was able to develop 450 W of power in 1 hour (area of solar panel 0.642 m^2). Power stored in the 12V 7 Ah battery (fully discharged) in 1 hour was computed as 83.88 W. Conversion efficiency of the solar panel (η) was found to be 18.6% which was calculated following Singh et al. (2022)

$$\eta = \frac{Total\ power\ stored\ in\ the\ battery}{Power\ developed\ by\ the\ solar\ panel} \quad (6)$$

Performance of battery during operation

The performance of the developed solar photovoltaic (SPV) powering system was assessed during detrashing operation in the daytime. Various parameters, including the power consumption of the detrasher, battery power, solar panel output power, and the corresponding solar intensity during the operation period, were measured. The solar radiation data were collected using an automated electronic Pyranometer. Throughout the operation, the solar intensity exhibited fluctuations within the range of 700 to 805 W/m^2. The power generated by the solar panels in an hour, which was utilized for the execution of the detrashing operation, ranged from approximately 435W to 455 W. Consequently, a discrepancy arose between the power demand for the detrashing process and the power supply provided by the solar photovoltaic (SPV) system. Therefore, this discrepancy was resolved by extracting energy from the battery. Nevertheless, the level of discharge from the battery did not correspond significantly to the chosen battery capacity. The battery's initial charge was at 100% before the operation. Following two hours of operation, approximately 20% of the battery's charge was depleted. During the weeding operation, the power demand for weeding was diminished as a result of the weeder resting or being turned off, leading to the utilization of the power generated by the panel to recharge the battery.

Performance of the Developed Sugarcane Detrasher

The output roller speeds were optimized for achieving improved detrashing efficiency and less percentage of trash left on the sugarcane stalk after the detrashing operation. Each observation was taken by setting the speed ratio between the motor and to detrashing roller is 1:1.2.

Effect of performance parameters on sugarcane stalk at a fixed speed ratio

The observed results were tabulated and given in Tables 1 and 2. The weight of the cane before detrashing, after detrashing, and the weight of the left on the cane after detrashing were measured, and the weight of the clean cane, the weight of the trash before detrashing, and the weight of the trash removed by the detrasher were calculated. The effect of detrashing efficiency, the output of the detrasher, and the trash left percentage on the sugarcane stalk with the speed of feeding rollers 1:1.12 speed ratio of motor-output roller were calculated.

Table 1. Test results during elevation trails of sugarcane detrasher

S. No.	Weight of the cane before detrashing (W_1), g	Weight of the cane after detrashing (W_2), g	The weight of the trash remained (W_3), g	Weight of the cleaned cane (W_4) = W_2-W_3	Weight of the trash before detrashing (W_5) = W_1-W_4	Weight of the trash removed (W_6) = W_5-W_3	Time taken for detrashing, s
1	1600.0	1400.2	35.5	1364.5	235.3	200	7.5
2	1784.6	1580.6	39.6	1540.4	244.2	204.6	7.8
3	1585.5	1372.5	35.5	1337	248.5	213	6.2
4	2098.3	1953.3	42.3	1911	187.3	145	7.9
5	1885.8	1750.8	36.5	1714.3	171.5	135	7.5

Table 2. Performance of sugarcane detrasher

S. No.	Trash content left on detached cane %, (W_3/W_5) ×100	Trash removal efficiency %	Output t/h (W_2 (kg)× 3600) / (1000 × t)
1.	15.08	84.91	0.67
2.	19.35	80.64	0.72
3.	16.66	83.33	0.79
4.	29.17	70.8	0.89
5.	27.03	72.96	0.84
6.	**Average**	**78.528**	**0.782**

Cost of Operation

The overall cost of the detrashing operation was conducted by incorporating both the ownership costs and operating costs. The American Society of Agricultural and Biological Engineers (ASABE) and the International Standard (IS) 9164-1979 were utilized to estimate machinery costs and then compared to the traditional methods employed by farmers, as well as the machinery options currently available in the market for this particular operation.

Manual garbage pickup on a cane averaged 28 minutes. The developed detrasher costs around 7,313 Rs/ha to detrash sugarcane, compared to 17500 Rs/ha for the traditional approach of Indian farmers. The developed equipment detrashes sugarcane in 78 man-h/ha, compared to 400 man-h/ha for the old approach. The above results show a 13.52% cost reduction and an 85.5% labour reduction. The developed machine costs roughly around 1,00,000/- less than market machines. The detrasher reduces human effort and expenses while the removal of trash from sugarcane.

4. Conclusion

A solar-powered sugarcane detrasher has been designed and developed. The developed machine has an average detrashing efficiency of 78.528% and an output capacity of 0.782 t/hr. The study highlights the potential environmental benefits of using renewable solar energy for agricultural operations. The study indicates a cost and labour reduction of 13.52% and 85.5% respectively. This research presents a novel approach to sugarcane detrashing using solar energy, which can significantly improve the efficiency and sustainability of sugarcane harvesting while reducing labor demands and environmental impact. The developed technology holds promise for enhancing agricultural mechanization in rural areas and promoting the adoption of renewable energy sources in agriculture.

5. Declaration of competing interest

The authors disclose that they have no known competing interests.

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