



RESEARCH ARTICLE

Response surface-based optimisation of design parameters in a cotton stalk harvesting machine

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Abstract

Cotton stalk management after harvest remains a critical challenge in Indian agriculture due to high labour requirements and environmental concerns associated with residue burning. This study presents a novel optimisation-driven design approach for a cotton stalk harvesting machine by integrating a laboratory-scale prototype with response surface methodology (RSM) to systematically evaluate and optimise key operational parameters. Unlike conventional approaches, this work establishes a quantitative relationship between machine design variables and performance indicators, enabling predictive optimisation for field applicability. The effects of peripheral speed, forward speed and blade type were investigated through 26 experimental runs, focusing on the bulk density and machine output of chopped cotton stalks. Results demonstrated that blade type and operational speeds significantly influenced performance, with strong interaction effects between peripheral speed and blade type at the 1 % significance level. Bulk density ranged from 143.85 to 249.38 kg m⁻³, while machine output varied between 211.3 and 573.5 kg hr⁻¹. The optimised parameter combination, consisting of a peripheral speed of 57.95 m s⁻¹, a forward speed of 2.21 km hr⁻¹ and L-type blade, yielded a predicted output of 573.67 kg hr⁻¹ and a bulk density of 255.27 kg m⁻³. Importantly, these optimised conditions provide practical operational benchmarks for field-scale implementation, demonstrating the potential to enhance chopping efficiency, reduce manual labour dependency and minimise environmental impacts. The study thus contributes a scalable and performance-validated framework for improving cotton residue management under real agricultural conditions.

Keywords: belt shaft; L-blade; response surface methodology; Y-blade

Introduction

Cotton (*Gossypium herbaceum* L.) is one of the most important commercial crops of India, cultivated widely in tropical and subtropical regions including America, Africa and Asia. After harvesting seed cotton, a large quantity of biomass known as cotton stalks remains in the field. In India, the annual production of crop residues is estimated at approximately 500 million tonnes, of which a significant portion is utilised as fodder or for energy generation; however, a surplus of about 140 million tonnes remains and nearly 92 million tonnes is burnt annually (1). The burning of crop residues releases harmful gases such as CO₂, CO, N₂O and NO⁺, contributing significantly to air pollution and environmental degradation (1).

Conventionally, cotton stalks are removed either by manual uprooting or cutting, which is highly labour-intensive and time-consuming. The labour requirement for manual stalk removal ranges from approximately 25–35 man-hr ha⁻¹, significantly increasing the cost of cultivation. Manual cutting and uprooting of the cotton stalk required 60 labourers and wages of Rs 3600 ha⁻¹ (2), posing additional challenges due to labour scarcity during peak agricultural seasons. Consequently, many small and marginal farmers resort to residue burning as a quick

and low-cost alternative because of limited access to appropriate machinery and lack of awareness.

Several cotton stalk management machines, such as tractor-operated shredders, rotary slashers and stalk pullers, have been developed and reported in the literature. However, these machines often suffer from limitations such as high cost, large size, high power requirement and reduced efficiency under varying field conditions. These constraints limit their adoption, particularly among small and marginal farmers, who require affordable, efficient and adaptable solutions.

To address these challenges, the development of an efficient cotton stalk harvesting machine is essential. Prior to full-scale field implementation, laboratory-based simulation studies play a crucial role in optimising design and operational parameters. Under actual field conditions, cotton stalks remain stationary while the machine moves forward to cut or shred them. In contrast, the present laboratory model consists of a stationary cutting (shredding) unit mounted on a rigid frame, with cotton stalks fed into the unit at controlled speeds to simulate field operation.

Response surface methodology (RSM) is an effective statistical tool for optimising complex processes involving multiple interacting variables while minimising the number of experimental

runs (3). In this study, RSM was employed to investigate the effects of forward speed, rotor speed (rpm) and blade type on performance parameters such as chopped length, bulk density, fineness modulus (uniformity) and machine output. The experimental design consisted of 26 runs with different combinations of independent variables.

Despite the availability of various cotton stalk management machines, there is a lack of systematically optimised design parameters tailored for efficient operation under small-scale farming conditions. Furthermore, limited studies have focused on laboratory-based simulation approaches to refine machine performance prior to field deployment. Most existing cotton stalk management machines, including tractor-operated shredders and mulchers, are primarily designed for *in situ* residue management, wherein the stalks are chopped and left in the field for decomposition. While such approaches are beneficial for soil incorporation, they do not facilitate the collection and utilisation of cotton stalk biomass for alternative applications such as fuel, briquetting or industrial use. In addition, some available machines are limited to single-row operation, resulting in lower field capacity and reduced operational efficiency.

In this context, the present study focuses on the optimisation of key design and operational parameters of a cotton stalk harvesting machine equipped with a collection system. This feature allows for *ex situ* utilisation of biomass, thereby enhancing the economic value of the crop residue.

Therefore, the present study aims to develop and optimise a cotton stalk harvesting machine through controlled laboratory experimentation, thereby providing a cost-effective and efficient solution suitable for wider adoption.

Materials and Methods

The design and operational parameters affecting the performance of cotton stalk harvesting machine were studied. To optimise the design parameters influencing the performance of cotton stalk harvesting machine, RSM was used to investigate the effects of design parameters on the responses. A laboratory model was developed for the optimisation of the design parameters. The development details of the laboratory model of the single-row machine used to optimise the design parameters are explained.

Operational parameters for laboratory machine

For harvesting thick-stemmed crops such as maize, bajra and sorghum, the recommended cutting speed is 40 m sec⁻¹ (4). The flail revolution of a flail-type forage harvester has been reported to lie in the range of 900–1600 rpm (5). However, all the above-mentioned recommendations are crop and field specific and may differ from crop to crop and field to field. Therefore, flail peripheral speed in the range of 900 (21 m sec⁻¹) to 2400 (58 m sec⁻¹) rpm was selected for this study.

Based on the above reviews and to optimise the operating parameters which, affect the performance of cotton stalk harvesting machinery, the following pertinent parameters with different levels were studied using the laboratory model machine.

Independent variables

Type of blade

Choosing the right blades in machines positively contributes to obtaining suitable particles sizes and reducing operating cost. Two types of blades (flails), namely Y-type and L-type blades, were used in this study (Fig. 1). The type of blade significantly influences

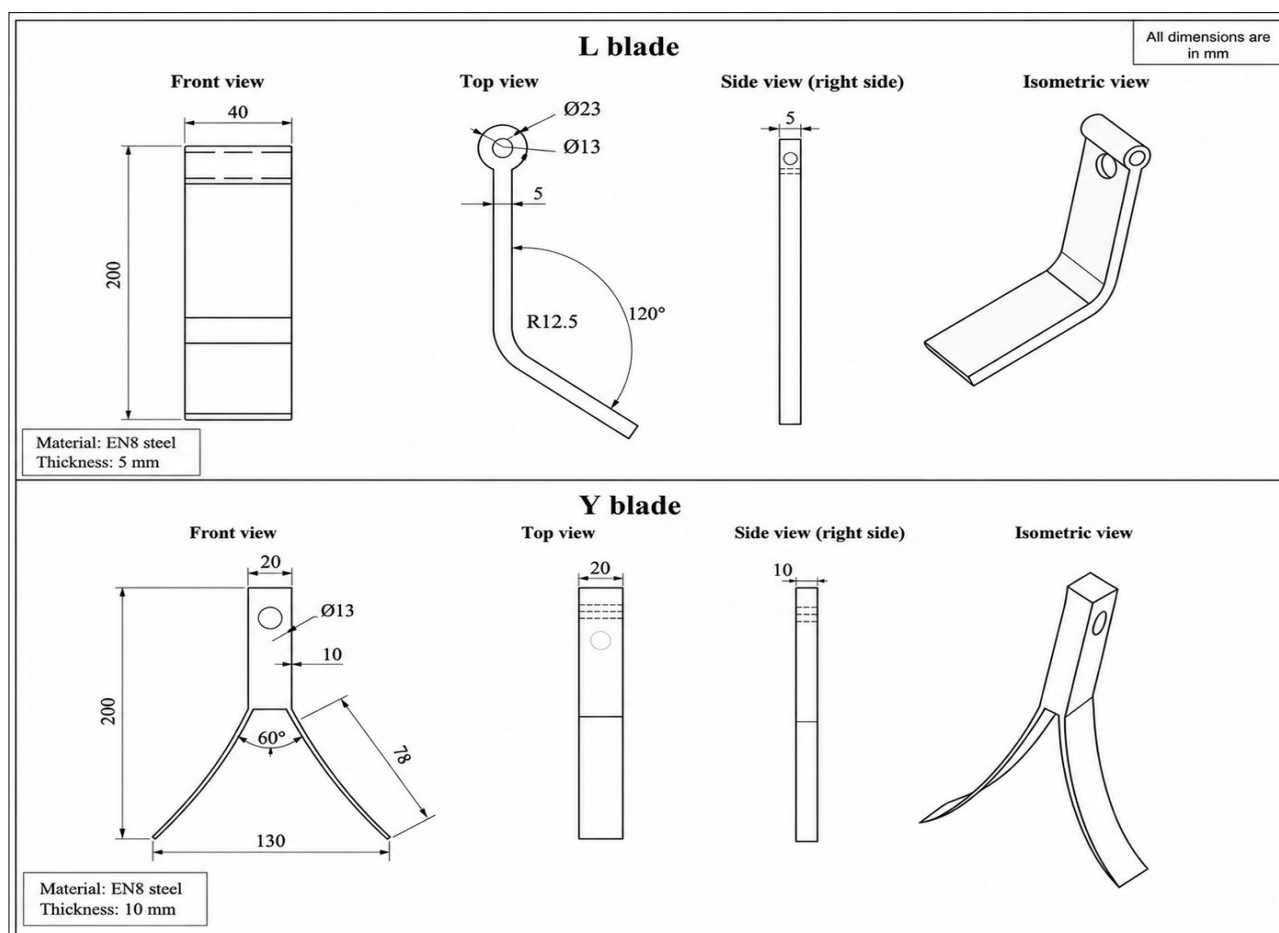


Fig. 1. Y-type and L-type blade.

the cutting mechanism and quality of cut. Different blade configurations affect the mode of interaction between the blade and the cotton stalk. A suitable blade type ensures efficient shearing or impact cutting, reduces uncut stalks and minimises clogging during operation. Under real field conditions, where stalk thickness and orientation vary, the appropriate blade design improves adaptability and ensures consistent performance. The harvesting blade was fabricated using EN8 steel, a medium-carbon steel known for its good strength, toughness and wear resistance. It offers a tensile strength in the range of 500–800 MPa and a yield strength of approximately 280 MPa, along with good impact resistance, making it suitable for applications involving dynamic and repetitive loading. To improve cutting efficiency and durability, the blade was subjected to heat treatment to enhance surface hardness while retaining sufficient core toughness. This treatment improves wear resistance, minimises edge deformation and ensures longer service life under field harvesting conditions. The selection of EN8 steel was based on its balanced combination of mechanical strength, machinability and cost-effectiveness, making it well suited for agricultural harvesting applications.

Peripheral speed

A peripheral speed of less than 20 m sec⁻¹ resulted in very less flail throw efficiency (6). Therefore, three higher levels of flail peripheral speed, namely 21, 38.5 and 58 m sec⁻¹ were selected for this study. Flail peripheral speed was varied by changing the pulley on the flail shaft of the cutting (shredding) unit. Blade peripheral speed determines the kinetic energy available for cutting the stalks. Higher peripheral speeds generally enhance cutting efficiency by providing sufficient impact or shear force to sever thicker and tougher stalks. However, excessively high speeds may lead to increased power consumption, wear of components and potential loss of collected material due to scattering. Therefore, optimising blade speed is essential to achieve a balance between effective cutting and energy efficiency under varying field conditions.

Forward speed

A shredder machine was recommended for removing residues of corn stalks at forward speeds between 2 and 4 km hr⁻¹ (7). Hence, three levels of forward speed of operation viz. 2, 3 and 4 km hr⁻¹ were selected for this study. The forward speed of the machine directly affects field capacity and the interaction time between the blade and the crop. At lower forward speeds, the machine achieves better cutting and collection efficiency due to increased residence time, but at the cost of reduced field capacity. Conversely, higher forward speeds increase operational efficiency but may result in incomplete cutting, missed stalks and reduced collection efficiency. Hence, optimising forward speed is critical to maintaining a balance between operational efficiency and performance quality in real field conditions.

Dependent variables

The effect of independent variables was assessed on the following dependent variables, which are indicators of the performance of the laboratory model machine.

- Bulk density of chopped cotton stalk
- Machine output

Bulk density of shredded cotton stalk

Bulk density represents the mass of collected biomass per unit

volume and is an indicator of how compactly the material is packed after harvesting. A higher bulk density is desirable as it facilitates efficient transportation and reduces the volume required for storage, thereby lowering logistical costs. In contrast, low bulk density material is bulky, difficult to handle and less economical for transport and further processing.

The cotton stalks chopped by the blades (flails) was filled into a box of known inner volume up to the top level and weighed. The bulk density was then calculated using the formula (6).

Bulk density (kg m⁻³) =

$$\frac{\text{Weight of box with cotton stalk} - \text{Weight of empty box}}{\text{Inner volume of box}}$$

Machine output

After each experiment, the entire quantity of shredded cotton stalks was collected in a polythene bag and the weight of the shredded cotton stalk was measured using a weighing balance. The machine productivity was calculated using the following equation (8):

$$P = \frac{W}{T}$$

Where, P_r = Machine productivity (kg hr⁻¹); W = weight of crop residue (kg); t = machine operating time (hr).

Design of the experiment

The operational parameters affecting the performance of the cotton stalk harvesting machine were optimised using RSM. Response surface methodology is a collection of mathematical and statistical techniques used for empirical model building. Response surface methodology is recognised as an important technique for optimising specific responses influenced by multiple variables. The RSM designs are primarily used not only for understanding the mechanism of the underlying system and assessing treatment main effects and interactions, but also for determining, within certain limits, the optimum operating conditions of a system (9). The conventional approach of conducting one-variable-at-a-time experimentation along with statistical analysis is highly labourious and time-consuming. The RSM is an effective technique for optimising complex processes, as it reduces the number of experiments required to evaluate multiple parameters and their interactions (3). Considering the experimental requirements, RSM was employed to investigate the influence of three different forward speeds, three different rpm levels and two different blade types on chopped length, bulk density, fineness modulus (uniformity) and machine output. A central composite design of RSM was used to optimise the parameters for the prototype machine. The design generated 26 experimental runs with different combinations of independent variables as shown in Table 1.

Development of laboratory model machine to optimise the design parameters

Agricultural machines are developed to operate in field conditions. Prior to machine development, a simulation experiment study at laboratory level will assist in developing a better machine. Under field conditions, cotton stalk remain stationary while the machine moves towards the stalks to cut (shred) them. In this laboratory study, cutting (shredding) unit was made stationary on a rigid L-angle frame and cotton stalks were moved into the cutting

Table 1. Design of experiment using response surface methodology for laboratory evaluation

Exp. No.	Peripheral speed (m sec ⁻¹)	Forward speed (km hr ⁻¹)	Blade
1	39.5	1.59	L
2	39.5	3	Y
3	39.5	3	L
4	39.5	3	Y
5	13.34	3	Y
6	39.5	1.59	Y
7	39.5	3	L
8	39.5	3	L
9	39.5	3	Y
10	39.5	3	Y
11	21	2	Y
12	21	2	L
13	65.66	3	L
14	39.5	3	L
15	39.5	4.41	L
16	39.5	3	Y
17	39.5	3	L
18	58	2	L
19	21	4	L
20	58	2	Y
21	39.5	4.41	Y
22	21	4	Y
23	65.66	3	Y
24	58	4	L
25	13.34	3	L
26	58	4	Y

(shredding) unit at predetermined speed. The cotton stalks were fixed on stalk holders riveted onto an endless belt. The cutting (shredding) unit consisted of blades (flails) fitted on a shaft driven by a 5 horsepower electric motor, the speed of which could be varied using a V belt and pulley arrangement according to the required peripheral blade (flail) speed. The cotton plants were harvested at the base from the field and are fixed in the cotton stalk holder of the belt which runs over two rollers. The drive roller is powered by a speed reducing gear box which driven by 3 horsepower electric motor through V belt drive. To avoid the sagging of the plant stalk carrying endless carrying belt, three numbers of idler rollers were provided at uniform distance (Fig. 2).

Experimental procedure

Experiments were conducted according to the combinations blade type, peripheral speed of the blade (flail) and forward speed furnished by each run. The shear strength and work by shear are lower when the moisture content of cotton stalk is in the range of 30–50 % (10). The moisture content at which, cutting energy is less and 95th percentile of stalk girth is selected for laboratory model study. After each experiment entire sample of chopped cotton stalks was collected in polyethene bag for measuring length of chopped stalk. The size of the stalks chopped by flails was categorised into four different ranges of sizes such as less than 50 mm, 50–100 mm, 100–150 mm and more than 150 mm (as shown in Fig. 3–6). The stalks less 50 mm were measured by a sieve of 50 × 50 mm aperture size sieve and the remaining sizes was measured using steel scale.

A total of 26 experimental runs were conducted using the laboratory model machine as designed through RSM and the mean chopped length, bulk density, fineness modulus (uniformity) and machine output were calculated for each run using the collected chopped cotton stalks. The experimental data values were analysed using the RSM design and the dependent parameters were optimised based on the specified boundary conditions for the response parameters.

Optimisation of operational parameter for cotton stalk harvesting machine in laboratory conditions

A numerical optimisation technique was used to optimise the operational parameters of the laboratory machine based on response constraints. The optimisation process was carried out using Design expert 7.0.0 version with RSM. The optimised parameters obtained from the laboratory study were considered for the development of the cotton stalk harvesting machine.

Results and Discussion

Development and study of laboratory model machine to optimise the design parameters

A laboratory model machine was developed to optimise the design parameters of a cotton stalk harvesting system under simulated conditions. The machine consists of a rigid rectangular main frame (6000 × 600 mm) fabricated using mild steel L-angles and mounted at a height of 450 mm above ground level to ensure structural stability. Along the frame, a rubber conveyor belt of 100 mm width and 3 mm thickness is mounted over pulley shafts supported on pedestal bearings, with idler rollers provided to prevent sagging. L-shaped stalk holders of size 135 × 80 × 2 mm are fabricated and riveted onto the belt at regular intervals to firmly hold cotton stalks using C-clamps during operation. The feeding mechanism is driven by a 3 horse power electric motor coupled with a gearbox (1:25 reduction) through a V-belt drive, enabling controlled variation of forward speed. The cutting unit comprises a main shaft of 720 mm length, incorporating a hollow flail shaft (60 mm outer diameter, 10 mm thickness, 500 mm length) with an internal solid shaft, mounted on a secondary rectangular frame of size 1660 × 450 mm. The shaft was supported on pedestal bearings and driven by a 5 horse power electric motor through a V-belt drive, allowing variation in blade tip speed by changing pulley combinations. Eight blade mounting brackets are welded circumferentially at 120° spacing on the shaft and blades (flails) are bolted onto these brackets. Two types of blades, namely L-type and Y-type fabricated from EN8 steel, were used in this study, each provided with a 35° bevel angle to enhance cutting efficiency. The entire setup enabled systematic variation of key operational parameters such as blade type, rotational speed (21–58 m s⁻¹) and

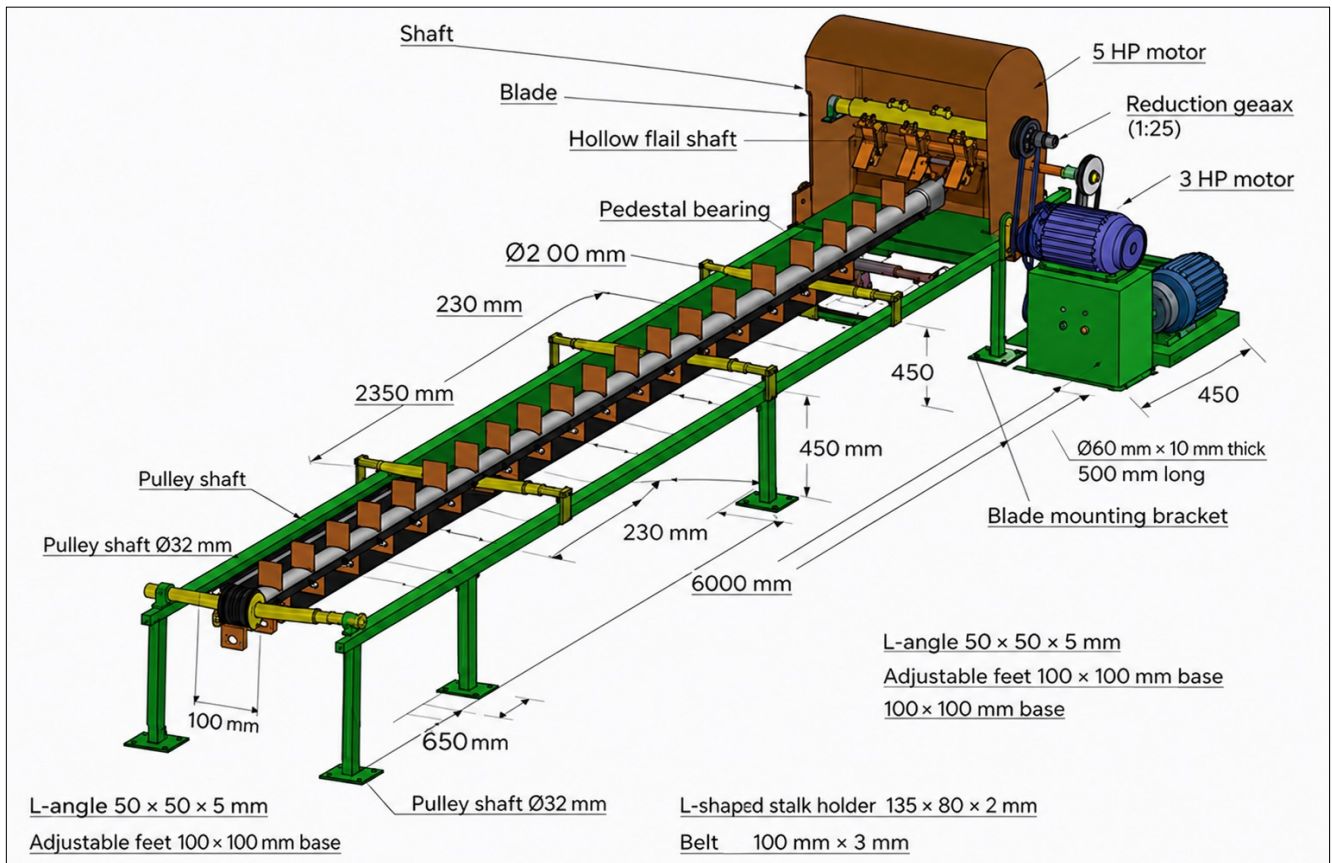


Fig. 2. Laboratory model assembly.

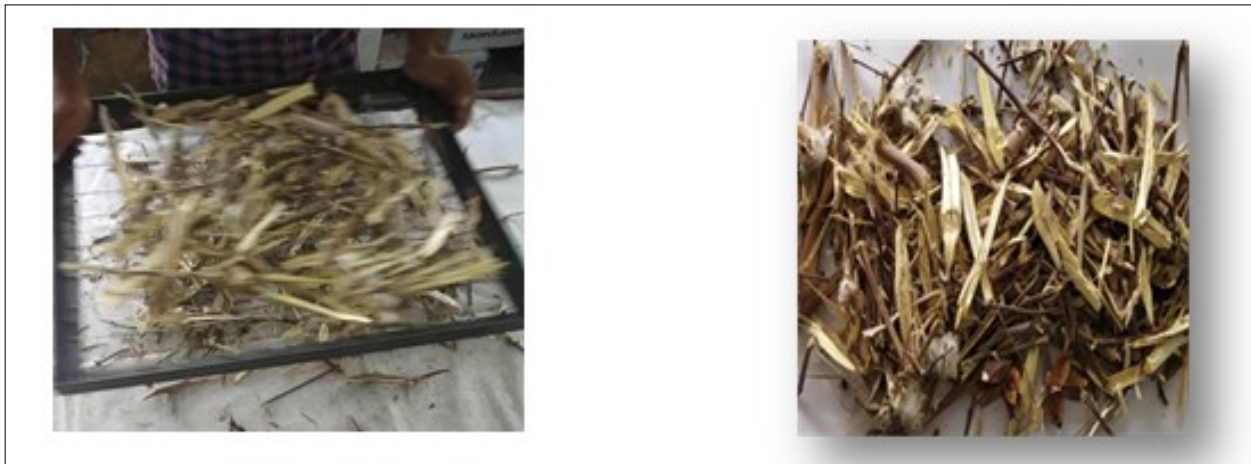


Fig. 3. Shredded cotton stalks of 0–50 mm length.

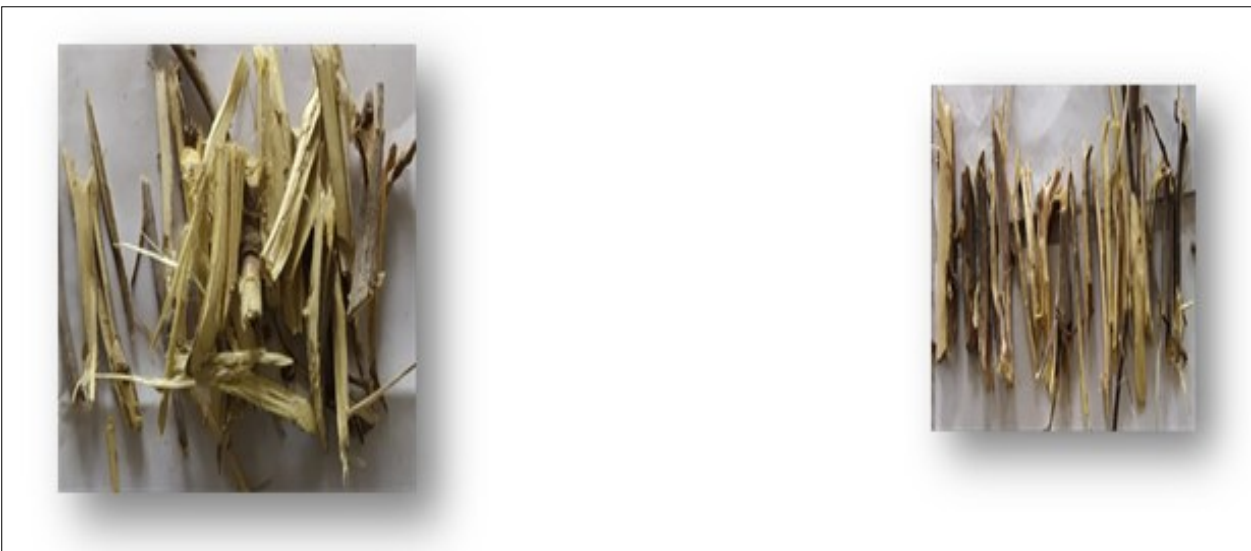


Fig. 4. Shredded cotton stalks of 50–100 mm length.

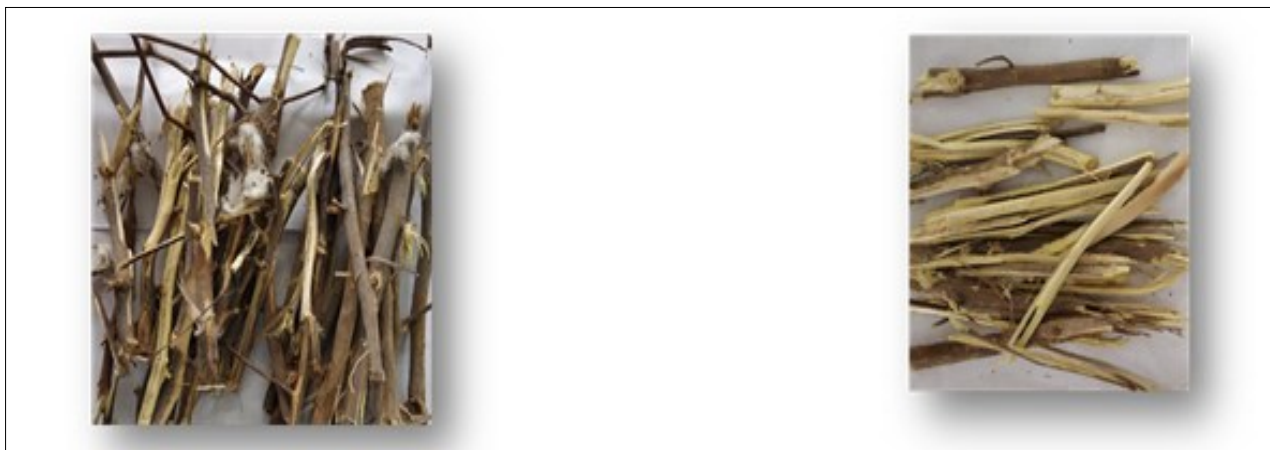


Fig. 5. Shredded cotton stalks of 100–150 mm length.



Fig. 6. Shredded cotton stalks of greater than 150 mm length.

forward speed, thereby facilitating optimisation studies under controlled laboratory conditions. As per the RSM design, the conveying speed of cotton stalks toward the shredding unit was varied in the range of 1.59–4.4 km hr⁻¹ to analyse its effect on chopping characteristics and machine performance.

Effect of forward speed (F) and peripheral speed (P) and type of blade (B) on bulk density

The effects of blade type, forward speed and peripheral speed are presented in Table 2. It was observed that bulk density varied from 143.85 to 249.38 kg m⁻³ with two types of blades, three different blade peripheral speeds and three different forward speeds. The maximum bulk density was observed at a peripheral speed of 39.5 m sec⁻¹, with L-type blade at forward speed of 1.59 km hr⁻¹ and the minimum bulk density was observed at a peripheral speed of 13.34 m sec⁻¹, with Y-type blade, at forward speed of 3 km hr⁻¹.

The individual and combined effect of two types of blades, three different blade peripheral speeds and three different forward speeds on bulk density was analysed statistically and are presented in Table 3. The quadratic polynomial model was applied for the analysis. The analysis revealed that the type of blade, peripheral speed and forward speed significantly influenced the bulk density at 1 % level of significance. The interaction effect of peripheral speed (P) × blade (B) was significant, whereas the remaining interaction effects, namely (P × F) and (F × B), were not significant on bulk density.

The *F*-value of the model was 91.25, indicating that the model was significant. The “Model *F*-value” could occur due to

noise with only by 0.01 % chance. The “Lack of Fit *F*-value” is 56.31, indicating that was significant. There was only a 0.01 % chance that a “Lack of Fit *F*-value” of this magnitude could occur due to noise. The “Pred *R*-Squared” value of 0.92 was in agreement with the “Adj *R*-Squared” value of 0.96. The signal-to-noise ratio, measured by Adeq Precision, was 29.41, which is greater than 4, indicating an adequate signal. Therefore, the model can be used to navigate the design space.

The effects of blade type, peripheral speed and forward speed are presented in Fig. 7 and 8. From the figures, it was observed that, for the L-type blade, an increase in peripheral speed and a decrease in forward speed resulted in an increase in bulk density. Similarly, for the Y-type blade, an increase in peripheral speed increased the bulk density, while a decrease in forward speed also increased the bulk density. The bulk density of shredded cotton stalks depended on the particle size. The trend of results is in consonance with the results reported in earlier studies (11, 12).

Effect of forward speed (F) and peripheral speed (P) and type of blade (B) on machine output

The effect of blade type, forward speed and peripheral speed on machine output are presented in Table 4. It was observed that machine output varied from 211.3 to 573.5 kg hr⁻¹ for two types of blades, three different blade peripheral speeds and three different forward speeds. The maximum machine output was observed at a peripheral speed of 58 m sec⁻¹, with the L-type blade at a forward speed of 2 km hr⁻¹, whereas the minimum machine output was observed at a peripheral speed of 39.5 m sec⁻¹ with the Y-type

Table 2. Effect of peripheral speed, forward speed and type of blade on bulk density

Exp. No.	Peripheral speed (m sec ⁻¹)	Forward speed (km hr ⁻¹)	Blade	Bulk density (kg m ⁻³)
1	39.5	1.59	L	249.381
2	39.5	3	Y	157.032
3	39.5	3	L	227.325
4	39.5	3	Y	156.023
5	13.34	3	Y	143.853
6	39.5	1.59	Y	165.313
7	39.5	3	L	229.414
8	39.5	3	L	229.142
9	39.5	3	Y	155.214
10	39.5	3	Y	153.031
11	21	2	Y	144.212
12	21	2	L	201.414
13	65.66	3	L	245.621
14	39.5	3	L	230.242
15	39.5	4.41	L	207.828
16	39.5	3	Y	155.901
17	39.5	3	L	229.162
18	58	2	L	248.925
19	21	4	L	198.425
20	58	2	Y	164.253
21	39.5	4.41	Y	147.239
22	21	4	Y	145.259
23	65.66	3	Y	161.215
24	58	4	L	228.205
25	13.34	3	L	159.322
26	58	4	Y	151.514

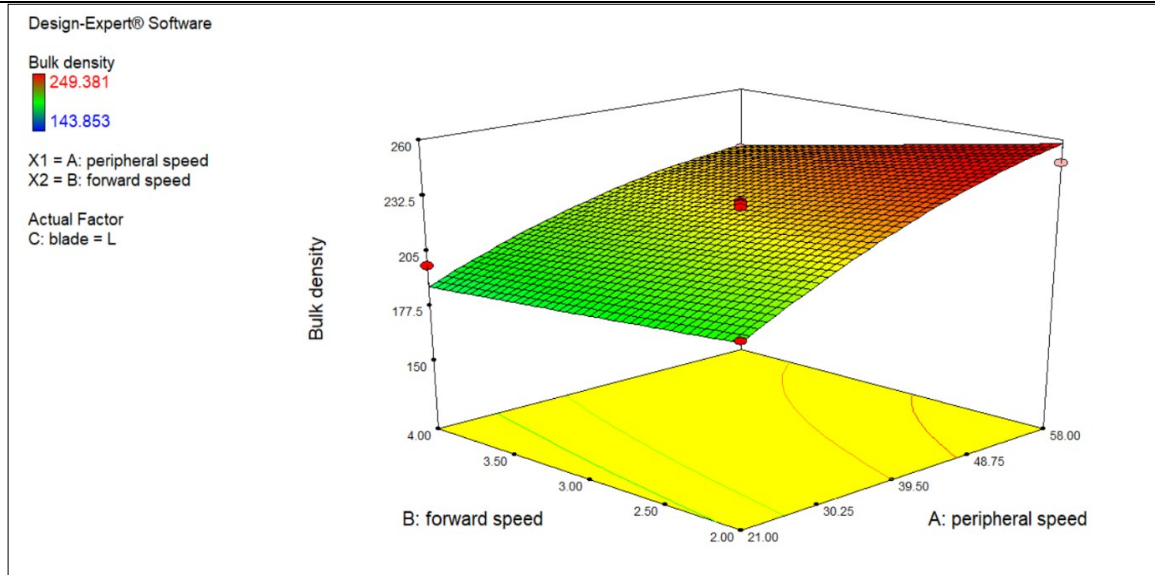
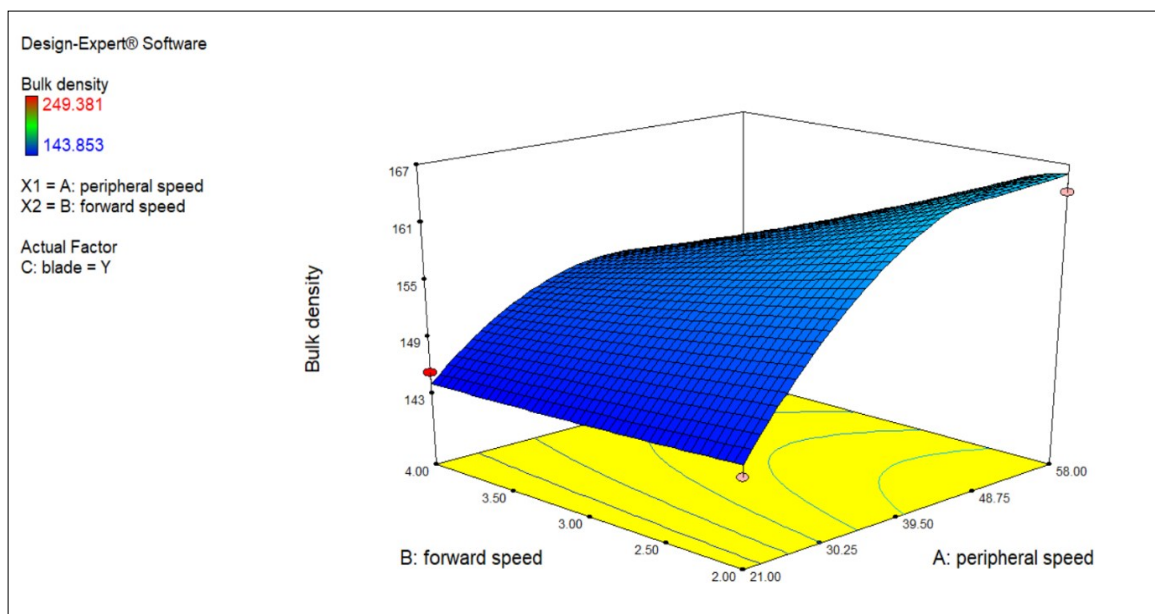
Table 3. Analysis of variance for bulk density of laboratory machine using response surface quadratic model

Source	Sum of squares	Degrees of freedom	Mean square	F-value	p-value	Significance
Model	37276.23	8	4659.52	91.24	<0.0001	Significant
Peripheral speed (P)	3912.05	1	3912.05	76.61	<0.0001	*
Forward speed (F)	895.90	1	895.90	17.54	0.0006	*
Blade (B)	30079.64	1	30079.64	589.06	<0.0001	*
P × F	124.17	1	124.17	2.43	0.13	NS
P × B	1378.01	1	1378.01	26.98	<0.0001	*
F × B	127.81	1	127.81	2.50	0.13	NS
P ²	740.78	1	740.78	14.50	0.0014	*
F ²	0.41	1	0.41	0.008	0.92	NS
Residual	868.08	17	51.06	–	–	–
Lack of fit	854.59	9	94.95	56.30	<0.0001	Significant
Pure error	13.49	8	1.68	–	–	–
Corrected total	38144.31	25	–	–	–	–
Model statistics	Value					
Mean	187.86					
Standard deviation	7.144					
CV (%)	3.80					
R ²	0.972					
Adjusted R ²	0.960					
Predicted R ²	0.929					
Adequate precision	29.41					

*Significant at $p < 0.01$ (1 % level of significance). CV: coefficient of variation; NS: not significant.

Table 4. Effect of peripheral speed, forward speed and type of blade on machine output

Exp. No.	Peripheral speed (m sec ⁻¹)	Forward speed (km hr ⁻¹)	Blade	Machine output (kg hr ⁻¹)
1	39.5	1.59	L	492.3
2	39.5	3	Y	255.2
3	39.5	3	L	535.6
4	39.5	3	Y	275.1
5	13.34	3	Y	226.2
6	39.5	1.59	Y	211.3
7	39.5	3	L	543.3
8	39.5	3	L	532.3
9	39.5	3	Y	255.7
10	39.5	3	Y	265.8
11	21	2	Y	221.3
12	21	2	L	271.2
13	65.66	3	L	566.2
14	39.5	3	L	546.1
15	39.5	4.41	L	567.2
16	39.5	3	Y	245.6
17	39.5	3	L	556.1
18	58	2	L	573.5
19	21	4	L	458.2
20	58	2	Y	361.2
21	39.5	4.41	Y	373.2
22	21	4	Y	242.1
23	65.66	3	Y	412.4
24	58	4	L	537.7
25	13.34	3	L	398.6
26	58	4	Y	423.4

**Fig. 7.** Bulk density as function of forward speed and peripheral seed for L-type blade.**Fig. 8.** Bulk density as function of forward speed and peripheral seed for Y-type blade.

blade at a forward speed of 1.59 km hr⁻¹.

The individual and combined effect of two types of blades, three different blade peripheral speeds and three different forward speeds, on machine output were analysed statistically and are presented in Table 5. The quadratic polynomial model was applied for the analysis. The analysis revealed that the type of blade, peripheral speed and forward speed significantly influenced the machine output at the 1 % level of significance. The interaction effect of forward speed (F) × blade (B) was significant, whereas the remaining interaction effects, namely (P × F) and (P × B) were not significant on machine output.

The *F*-value of the model was 21.79, indicating that the model was significant. The “Model *F*-value” could occur due to noise with only a 0.01 % chance. The “Lack of Fit *F*-value” was 41.40, indicating that it was significant. There was only a 0.01 % chance that a “Lack of Fit *F*-value” of this magnitude could occur due to noise. The “Pred *R*-Squared” value of 0.73 was in agreement with the “Adj *R*-Squared” of 0.86. The signal-to-noise ratio, measured by Adeq Precision, was 15.77, which is greater than 4, indicating an adequate signal. Therefore, the model can be used to navigate the design space (9, 13).

The effects of blade type, peripheral speed and forward speed are presented in Fig. 9 and 10. From the figures, it was observed that, for the L-type blade, an increase in the peripheral speed and forward speed increased the machine output. Similarly, for the Y-type blade, an increase in peripheral speed increased the machine output and an increase in forward speed also resulted in increased machine output. An increase in forward speed increased the number of stalks shredded per unit time, which consequently increased the machine output. Similar trends have been reported in earlier studies (14, 15).

Optimisation of parameters

The experiments were conducted to optimise the operational parameters, namely peripheral speed, forward speed and type of blade. The performance parameters selected for optimisation process were mean chopped length, bulk density, fineness modulus and machine output. The goal was set to minimise the

mean chopped length and fineness modulus and maximise bulk density and machine output.

A numerical optimisation technique was used to optimise the operational parameters of the laboratory machine based on response constraints. The constraints used for the optimisation experiment are presented in Table 6. The optimised operational parameters, along with the predicted values of the response variables, are presented in Table 7.

The optimised parameters for the laboratory machine were a peripheral speed of 57.95 m s⁻¹, L-type blade and a forward speed of 2.21 km hr⁻¹. The predicted values of the responses under optimised conditions were a mean chopped length of 109.3 mm, fineness modulus of 1.56, bulk density of 255.265 kg m⁻³ and machine output of 573.67 kg hr⁻¹. Further field evaluation was conducted at the optimised operational parameters and the actual values of the performance parameters were measured. The actual values were compared with the predicted values and the percentage variation was calculated (Table 8).

Conclusion

A laboratory model of a cotton stalk harvesting machine was developed to optimise key design and operational parameters influencing its performance. Using response surface methodology (RSM), the effects of peripheral blade speed, forward speed and blade type on bulk density and machine output were systematically analysed. The results indicated that these factors had significant individual and interaction effects, with higher peripheral speeds and L-type blades improving performance. The optimal combination, comprising a peripheral speed of 57.95 m sec⁻¹, forward speed of 2.21 km hr⁻¹ and L-type blade resulted in a maximum bulk density of 255.26 kg m⁻³ and machine output of 573.67 kg hr⁻¹, with good agreement between the predicted and experimental values.

However, the present study is limited to controlled laboratory conditions and did not account for field variability, such as soil conditions, crop heterogeneity and varying moisture levels during actual harvesting. In addition, long-term blade wear,

Table 5. Analysis of variance for machine output of laboratory machine using response surface quadratic model

Source	Sum of squares	Degrees of freedom	Mean square	<i>F</i> -value	<i>p</i> -value	Significance
Model	41.91	8	5.23	21.78	<0.0001	Significant
Peripheral speed (P)	9.051	1	9.051	37.63	<0.0001	*
Forward speed (F)	2.024	1	2.024	8.41	0.0099	*
Blade (B)	30.36	1	30.36	126.28	<0.0001	*
P × F	0.41	1	0.41	1.71	0.20	NS
P × B	0.007	1	0.007	0.03	0.86	NS
F × B	0.014	1	0.014	0.078	0.78	NS
P ²	0.03	1	0.03	0.14	0.70	NS
F ²	8.7E-09	1	8.7E-09	3.62E-08	0.99	NS
Residual	4.08	17	0.24	–	–	–
Lack of fit	4.001	9	0.44	41.39	<0.0001	Significant
Pure error	0.08	8	0.01	–	–	–
Corrected total	46.001	25	–	–	–	–
Model statistics	Value					
Mean	3.97					
Standard deviation	0.49					
CV (%)	12.32					
R ²	0.91					
Adjusted R ²	0.86					
Predicted R ²	0.73					
Adequate precision	15.77					

*Significant at *p* < 0.01 (1 % level of significance). CV: coefficient of variation; NS: not significant.

Table 6. Multi response numerical optimisation constraints for laboratory machine

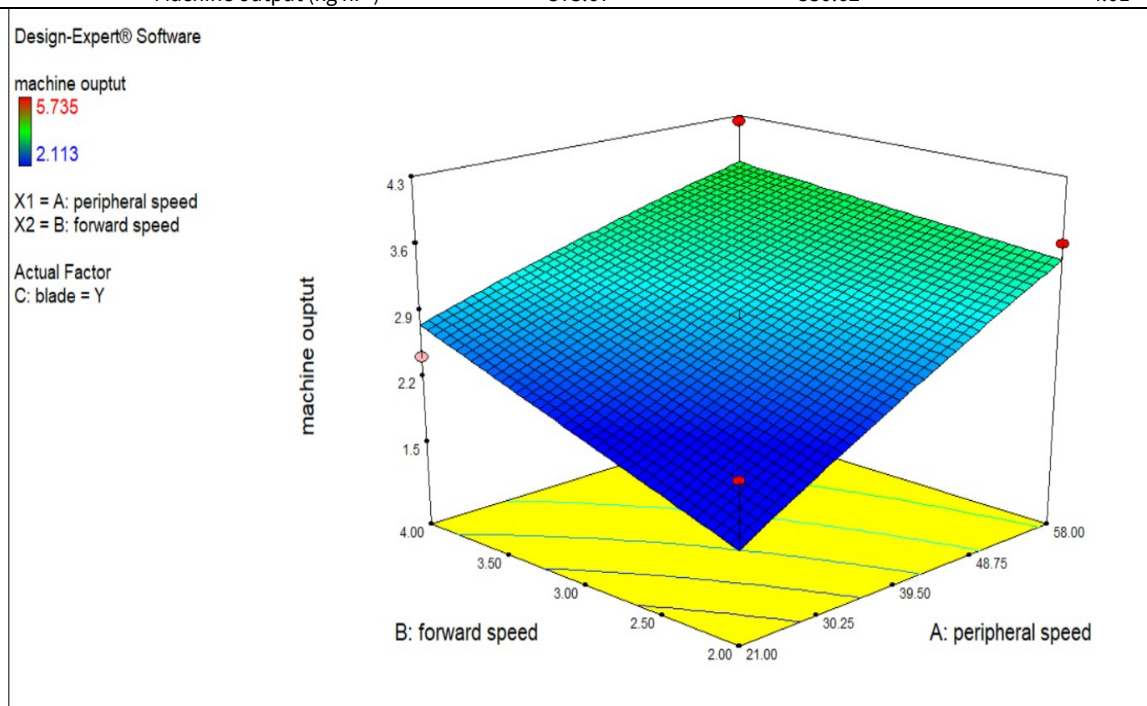
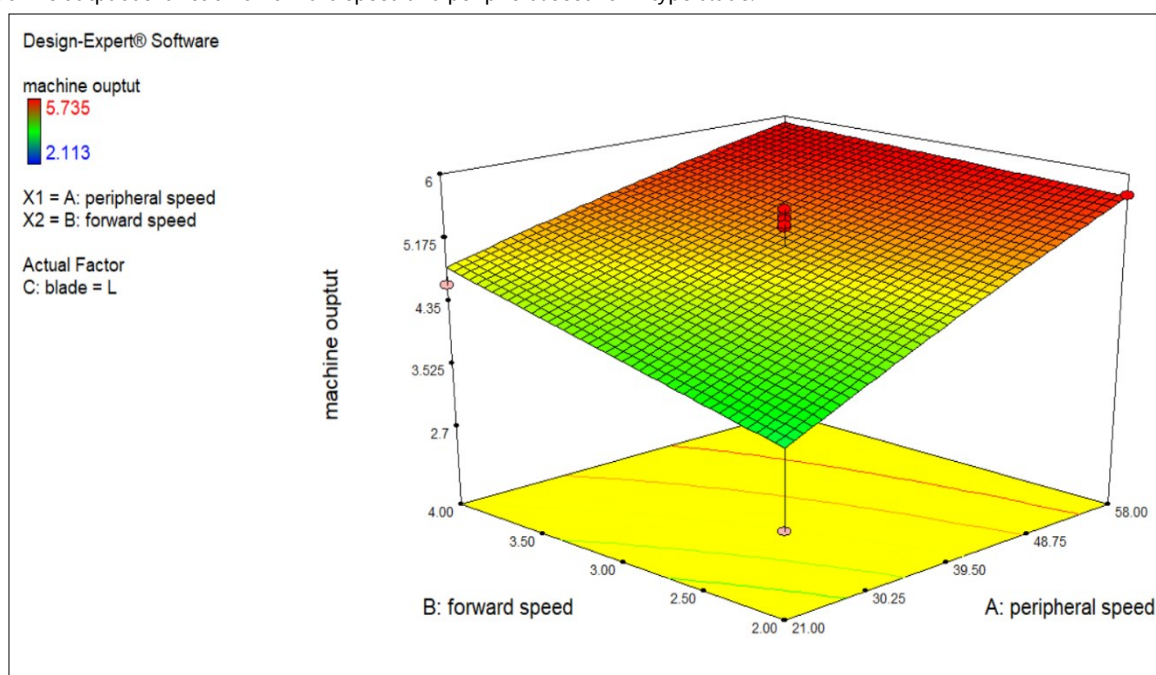
Name	Goal	Lower limit	Upper limit	Importance
Peripheral speed (m s^{-1})	Is in range	21	58	3
Forward speed (km hr^{-1})	Is in range	2	4	3
Blade	Is in range	Y	L	3
Bulk density (kg m^{-3})	Maximise	143.853	249.381	3
Machine output (kg hr^{-1})	Maximise	211.3	573.5	3

Table 7. Optimum values of mean chopped length, fineness modulus, bulk density and machine output

Sl. No.	Peripheral speed (m s^{-1})	Forward speed (km hr^{-1})	Blade	Chopped length (mm)	Fineness modulus (uniformity)	Bulk density (kg m^{-3})	Machine output (kg hr^{-1})	Desirability	Optimisation Status
1	57.95	2.21	L	108.79	1.561	255.265	573.67	1	Selected
2	57.97	2.24	L	109.45	1.571	254.723	574.13	1	
3	57.78	2.27	L	110.16	1.580	254.183	573.51	1	
4	57.97	2.22	L	109.06	1.565	255.037	573.94	1	

Table 8. Predicted and actual values of responses under optimised treatment combination

Sl. No.	Particulars	Predicted values	Actual values	Percent variation
1	Bulk density (kg m^{-3})	255.265	242.56	4.97
2	Machine output (kg hr^{-1})	573.67	550.62	4.01

**Fig. 9.** Machine output as function of forward speed and peripheral seed for Y-type blade.**Fig. 10.** Machine output as function of forward speed and peripheral seed for L-type blade.

energy consumption and machine durability were not evaluated. Future research should focus on field-scale validation of the developed system, assessment of performance under diverse crop and environmental conditions and integration of the optimised parameters into a tractor-operated prototype. Further studies on blade design refinement, energy efficiency and real-time performance monitoring using sensor-based systems may enhance the applicability and commercial viability of the developed machine.

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Authors' contributions

CSK designed and conducted the experiment, performed data collection and drafted the manuscript. KVP contributed to the conceptualisation of the study, guided the methodology and assisted in manuscript revision. SR and S provided technical inputs and support in data analysis. PV assisted in experimental setup and result validation. DK contributed to data interpretation and critical review of the manuscript. MN supervised the overall work, provided necessary facilities and reviewed the final draft. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

- Bhuvaneshwari S, Hettiaarachchi H, Meegoda JN. Crop residue burning in India: policy changes and potential solutions. *J Environ Res Public Health*. 2019;16(5):832. <https://doi.org/10.3390/ijerph16050832>
- Raja D, Kalarani MK, Janaki P. Impact of farm implements in cotton cultivation. *Agric Update*. 2009;4(1-2):62-4.
- Lee WC, Yousuf S, Hamid NSA, Baharin BS. Optimizing conditions for enzymatic clarification of banana juice using response surface methodology (RSM). *J Food Eng*. 2006;73:53-63. <https://doi.org/10.1016/j.jfoodeng.2005.01.005>
- Dubler K. Impact cutting in mowing forage crops. *Hohenheimer Arbeiten*. 1972;62:55-60.
- Kanafojski C, Karwowski T. Agricultural machines, theory and construction. *Crop-harvesting machines*. Vol. 2. Warsaw (Poland): National Center for Scientific, Technical and Economic Information; 1976.
- Goyal R, Mahal JS, Manes GS. Performance evaluation of flail unit of forage harvester on sorghum fodder. *Agric Res J*. 2016;53(2):264-7. <https://doi.org/10.5958/2395-146X.2016.00049.1>
- Eltarhuny MM, Fouda T. Utilization of self-propelled harvester and shredder machines for removing some field crop residues. *Manag Econ Eng Agric Rural Dev*. 2012;12(1):67-70.
- Omran MS. Study of the performance of the most widely used shredders for crop residues in Egypt. In: *Proceedings of the 15th Annual Conference of the Misr Society of Agricultural Engineering*, 2008 Dec 12-13, Egypt; 2008.
- Myers RH. *Response surface methodology*. Boston (MA): Allyn and Bacon Inc.; 1971. p. 1-69.
- Li Y, Du X, Song Z, Li F. Test of shear mechanical properties of cotton stalks. *Trans Chin Soc Agric Eng*. 2011;27(2):124-30.
- Ghorbani Z, Hemmat A, Masoumi AA. Physical and mechanical properties of *alfalfa* grind as affected by particle size and moisture content. *J Agric Sci Technol*. 2012;14:65-76.
- Świętochowski A, Lisowski A, Dąbrowska-Salwin M. The effect of particle sizes on the density and porosity of the material. In: *Proc Int Conf Trends Agric Eng*, 2016 Sep 7-9, Prague, Czech Republic; 2016. p. 609-14.
- Montgomery DC. *Design and analysis of experiments*. 9th ed. New York: Wiley; 2017.
- El-Khateeb HA, El-Keway AA. Development and evaluation of cutting knives to suit cutting wet and dry field residues. *J Soil Sci Agric Eng Mansoura Univ*. 2012;3(6):601-16. <https://doi.org/10.21608/jssae.2012.54339>
- Mady MA, Abdel-Hadi MA, Abd-Allah YE, Ali MF. A study on some engineering parameters of cutting and chopping machine for agricultural wastes. *Misr J Agric Eng*. 2015;32(4):1775-800. <https://doi.org/10.21608/mjae.2015.97881>

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