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Laboratory evaluation of cotton stalk shredder

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Abstract
Cotton is a significant economic crop in India, and within the country, Karnataka is the ninth most prominent state for cotton cultivation. It boasts a total cultivable land of 5.46 lakh hectare and a production potential of 29%. However, the production of cotton stalk per hectare is a staggering 10,000 kg, which is often considered a waste product and burned. Unfortunately, such burning leads to various health problems and global warming. To tackle this issue of agricultural waste management, the cotton stalk shredder was evaluated in laboratory conditions. The parameters were optimized under laboratory conditions, including the number of blades (2, 3, and 6), feed rate (152, 193, and 220 kg h^{-1}), and peripheral speed (34.88, 38.75, and 42.63 m s-1). The evaluation was based on the length of cut, power requirement, and specific shredding energy. Ultimately, it was determined that the optimal configuration for shredding cotton stalk was six blades, a feed rate of 152 kg h^{-1}, and a peripheral speed of 34.88 m s-1. The resulting length of cut, power requirement, and specific shredding energy were 28 mm, 3.82 kW, and 0.164 MJ kg^{-1}, respectively.

Keywords: Cotton stalk shredder, length of cut, peripheral speed and specific shredding energy

Introduction
Cotton is grown commercially over 111 countries throughout world. India stands second place in cotton production. The global area under cotton cultivation is 33.2 Mha accounting for 18.9 Mt of cotton (Anon., 2018) [3]. More than 250 million people are supported by the production, processing, and marketing of cotton, which accounts for 45% of the world's textile output.
Cotton is one of the important economic crop in India with production potential of 370 lakhs 0f bales. Karnataka is the ninth major cotton growing state in the country with total cultivable land of 5.46 lakh hectare and 6.75% of the cotton-growing land around 29% of the cotton production are in Karnataka. The major varieties/hybrids of cotton grown in the state include Abhadita, laxmi, LRA-5166, Jayadhar, NHH-44, DHH-11, DCH-32, DHB-105 and release of several hybrids and varieties by private companies like JK, Mahyco etc., In Karnataka, hybrids and high yielding varieties are cultivated in the districts of Raichur, Bagalkot, Bijapur, Bellari, Dharwad and Belgaum under rainfed conditions (with assured rainfall). While, irrigated cotton is predominantly grown in Dharwad, Belgaum, Shimoga, Mysore and Karwar. Irrigated cotton area in the state was about 20%. The area under was 5.46 lakh hectares with a production of 18 lakhs bales (170 kg each) during 2017-2018 (Anon., 2018) [3]. The cotton productivity was 560.44 kg per hectare in the same period.
Each year, around 500 Mt of crop leftovers are produced (Anon., 2009) [2]. Various estimates place the amount of crop leftovers burned on farms between 72 and 127 Mt. (Mehta 2004, Pathak 2006, Pathak *et al*., 2010) [4, 5-6]. Burning leftovers causes a wide range of issues, including the generation of soot particles and smoke that can be harmful to human health, the emission of greenhouse gases including carbon dioxide, methane, and nitrous oxide that contribute to global warming, and the depletion of plant nutrients. In cotton cultivation, cleaning of stalk in field for next crop is labour consuming and drudgery work. Cotton stalk shredder is optimised on laboratory condition to run in field for proper shredding of cotton stalk.

Materials and Methods
Laboratory evaluation of developed cotton stalk shredder
The laboratory evaluation was carried out in the department of FMPE at CAE, Raichur. The independent variables selected for study were at three levels as per the factorial completely randomized block design (CRBD) and 27 experiments were conducted. To calculate error between the responses and independent variables, three replicated experiments were conducted (Plate 1).

Plate 1: Laboratory evaluation of cotton stalk shredder

An experimental arrangement was established to imitate the operating parameters under laboratory conditions. The developed test rig comprised of several key components, including a 5.88 kW, AC three phase induction motor as the power source, an electrical motor driving the cotton stalk shredder assembly through a V-belt, and an instrumentation assembly. The wattmeter, with a capacity of 8.2 kW, was situated between the power source and the cotton stalk shredder via a coupler, and was used to detect power during the shredding process. Analog type power indicators were employed to monitor the power, and the wattmeter was pre-calibrated through the application of known power. Power readings were recorded during the cutting of the stalks, which were fed manually at the root level. The cotton stalk shredder was fixed at one end of the frame, and the shredder blades, sized at 335 × 80 × 5 mm, applied the cutting force on the material.

The blades were tested at three levels of peripheral speeds, namely 34.88, 38.75, and 42.63 m s-1. Notably, two different sizes of driven and drive pulleys, measuring 203.20 mm and 101.60 mm, respectively, were employed in the test rig. The power transmission system utilized a V-belt and pulley to achieve the transfer of energy from the electrical motor to the cotton stalk shredder assembly. This resulted in the cotton stalk shredder rotating continuously and without any discernible vibration, thus enabling the efficient cutting of the cotton stalk. The test rig frame was constructed using C channel of size 100 x 50 x 50 x 6 mm and L angle of size 40 x 40 x 6 mm. The functional components of the test rig were firmly affixed over the frame assembly, which provided unwavering support and eliminated any potential for vibration during the course of the trials.

Selection of variables

The identification of important variables for laboratory evaluation of the developed cotton stalk shredder included the number of blades, peripheral speed, and feed rate. For the laboratory evaluation of the cotton stalk shredder, three levels of variables were selected. These independent variables, namely the number of blades, peripheral speed, and feed rate, were carefully considered and explained as follows.

The power requirement of shredders heavily relies on the number of blades as they consume a significant portion of the total energy required for operation. Thus, three levels of blades on the shredding plate, namely 2, 3, and 6, were taken into account. Accordingly, three levels of the number of blades were selected for the laboratory evaluation of the developed cotton stalk shredder (Senthilkumar *et al*., 2010) [8]. Feed rate, on the other hand, pertains to the amount of material that was fed into the machine per unit time. The feed rate was calculated based on the forward speed of the tractor, with three different forward speeds considered, namely 3, 3.5, and 4 km h^{-1}. For the laboratory study, feed rate was considered at three different levels, namely 152, 193, and 220 kg h^{-1}. The feed rate was computed using the following formula.

$$\text{Feed rate, kg h}^{-1} = \frac{S \times M}{W_P} \quad (3.5)$$

Where,
S = Forward speed, km h^{-1}
M = Mass of one plant, kg
W_P = Plant to plant spacing, m

An electric motor was implemented to power the cotton stalk shredder, whereby the peripheral speed of the shredding unit was manipulated via alterations in the rotational speed of the motor. For purposes of the laboratory investigation, three distinct levels of peripheral speed were selected: specifically, 34.88, 38.75, and 42.63 m s-1 (Senthilkumar *et al*., 2010) [8].

Performance parameters

The performance parameters of the cotton stalk shredder, including the length of cut, power requirement, and specific shredding energy, were identified as dependent variables and subsequently determined as detailed below. The length of cut is a crucial dependent variable that significantly impacts the decomposition of shredded cotton. Smaller cut pieces result in faster decomposition (Plate 2).

To calculate the length of cut, a sample of shredded cotton stalk was collected and divided into four categories based on the size of the cotton pieces: L1 = <10 mm, L2 = 11-25 mm, L3 = 26-35 mm, and L4= 36-150 mm. The weight of each size sample was considered as the length of cut pieces of shredded cotton. The sample was collected, and the length of the chopped material was measured using a scale. The weighted average length of cut was calculated as outlined in Patil *et al*. (2004) [7].

$$L = \frac{L_1W_1 + L_2W_2 + L_3W_3 + L_4W_4}{W_1 + W_2 + W_3 + W_4} \quad (3.6)$$

Where,
L = Length of cut pieces of shredded cotton, mm
L_1 to L_4 = Lengths of each categories, mm
W_1 to W_4 = Weight of each categories, kg

The specific energy utilized during the shredding process was determined by coupling the driving motor to a wattmeter to measure the consumed power. The entirety of the power consumption during the shredding process was recorded by the wattmeter reading. The average power required to operate the shredder was determined to be 0.5 kW, while the power of the driving motor was measured at 5.5 kW. Utilizing these values, the net power was estimated and the specific shredding energy was subsequently calculated by means of a prescribed formula.

(a) (b)

(c) (d)

Plate 2: Different lengths of shredded cotton stalk (a) <10 mm (b) 11-25 mm (c) 26-35 mm (d) 36-150 mm

$$P_N = (P_S - P_B) + P_H$$

$$E_N = \frac{P_N \times t}{M} \times 3.6 \quad (3.7)$$

Where,
P_N = Net power, kW
P_S = Wattmeter reading, kW
P_B = Average power required, kW
P_H = Power of the driving motor, kW
E_N = Specific shredding energy, MJ kg^{-1}
t = Net exposure time, h
M = Shredded mass, kg

During the operation of the cotton stalk shredder, a wattmeter was employed to determine the power requirement necessary to effectively shred the aforementioned stalk. The value representing the power requirement was subsequently displayed on the wattmeter.

Optimization of machine and operational parameters of cotton stalk shredder

Optimum process conditions are required to significantly enhance the performance of cotton stalk shredder. Numerical optimization has been conducted to evaluate the optimum number of blades, feed rate and peripheral speed. In this study, different levels of each independent variable *viz*., number of blades, feed rate and peripheral speed were used for the design of experiments to study their effects on length of cut, specific shredding energy and power requirement.

The performance evaluations were carried at three levels of number of blades (2, 3 and 6), peripheral speed (34.88, 38.75 and 42.63 m s^{-1}) and feed rate (152, 193 and 220 kg h^{-1}). The dependent variables taken for cotton stalk shredder were length of cut, specific shredding energy and power requirement. A three factor randomized block design technique were used to analyse the effect of number of blades, feed rate and peripheral speed on the performance of cotton stalk shredder.

Results and Discussion

Effect of number of blades, peripheral speed and feed rate on length of cut

The length of cut of stalk varied from 26 to 57 mm at different number of blades for different peripheral speed and feed rate. The minimum length of cut 26 mm was recorded with 6 number of blades at 42.63 m s^{-1} peripheral speed for 152 kg h^{-1} feed rate whereas the maximum length of cut 57 mm was observed with 2 number of blades at 34.88 m s^{-1} for peripheral speed and 220 kg h^{-1} feed rate. The mean value of length of cut was found to be 38 mm. The effects of different number of blades and peripheral speed on length of cut of cotton stalk at different feed rate are presented in Fig. 1, 2, 3. From the figures it was observed that the length of the cut dropped with increasing the number of blades, peripheral speed, and feed rate. Length of cut dropped with increase in number of blades and peripheral speed due to increase in number of cuts per unit time. Length of cut increased as feed rate increased since more stalks needed to be chopped in a given amount of time. These results are in agreement with Alaa *et al.* (2016) [1] and Senthilkumar *et al.* (2010) [8].

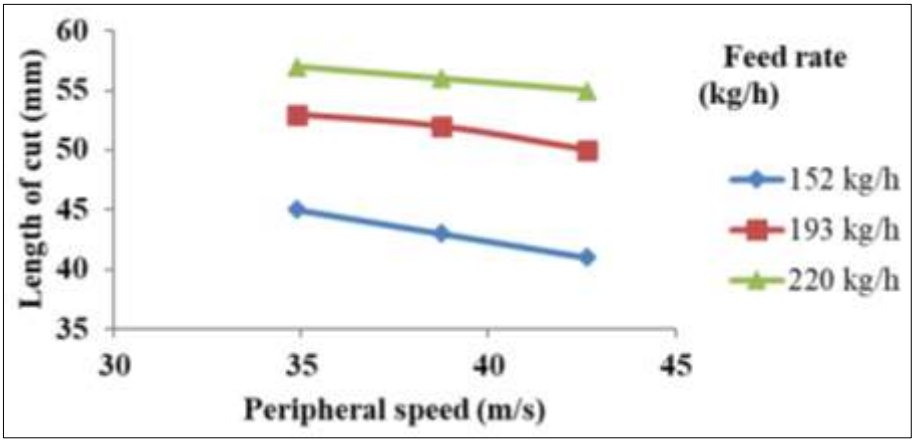

Fig 1: Effect of peripheral speed on length of cut at different feed rate with 2 number of blades

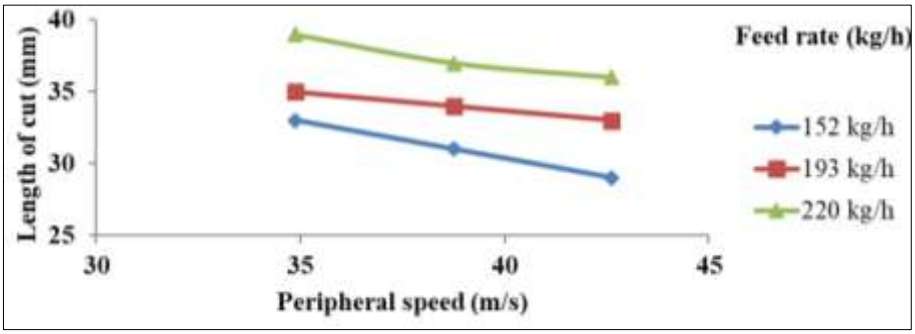

Fig 2: Effect of peripheral speed on length of cut at different feed rate with 3 number of blades

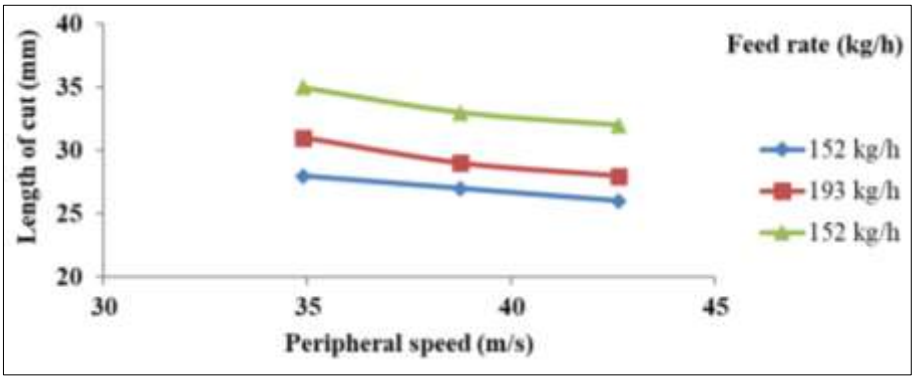

Fig 3: Effect of peripheral speed on length of cut at different feed rate with 6 number of blades

Effect of number of blades, peripheral speed and feed rate on specific shredding energy

The specific shredding energy of cotton stalk shredder varied from 0.144 to 0.295
MJ kg^{-1} with different number of blades, peripheral speed and feed rate. The minimum specific shredding energy of 0.144 MJ kg^{-1} was recorded with 2 number of blades at 34.88 m s^{-1} peripheral speed for 152 kg h^{-1} feed rate whereas the maximum specific shredding energy of 0.295 MJ kg^{-1} was found at 6 number of blades, 42.63 m s^{-1} peripheral speed and 220 kg h^{-1} feed rate. The mean value of specific shredding energy was found to be 0.205 MJ kg^{-1}. The effects of different number of blades, peripheral speed and feed rate on specific shredding energy are presented in Fig. 4, 5, 6. From the

figures it was observed that specific shredding energy of cotton stalk shredder increased with increase in number of blades, peripheral speed and feed rate. Specific shredding energy was highest with 6 number of blades. Specific shredding energy increased with increase in number of blades and peripheral speed due to excessive load on blades at high peripheral speed of cutting. Specific shredding energy increased with increase in feed rate due to increase in impact energy required to cut more stalks per unit time. These results are in agreement with Alaa *et al.* (2016) [1] and Senthilkumar *et al.* (2010) [8].

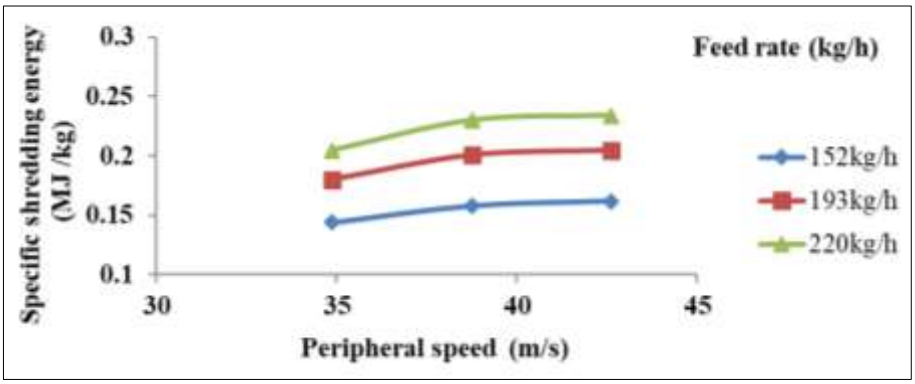

Fig 4: Effect of peripheral speed on specific shredding energy at different feed rate with 2 number of blades

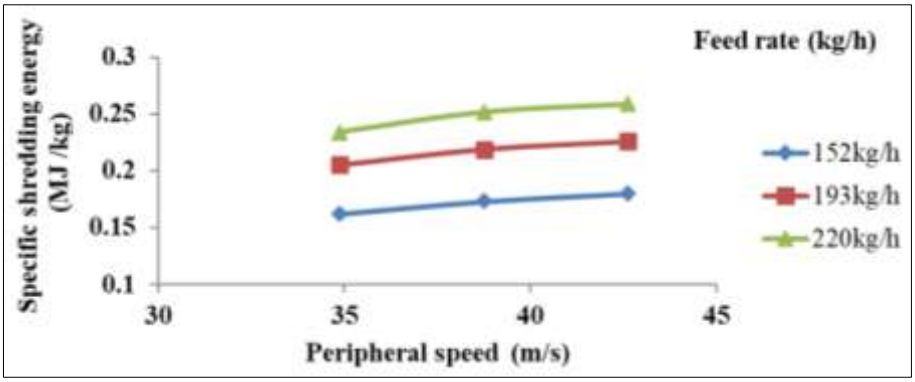

Fig 5: Effect of peripheral speed on specific shredding energy at different feed rate with 3 number of blades

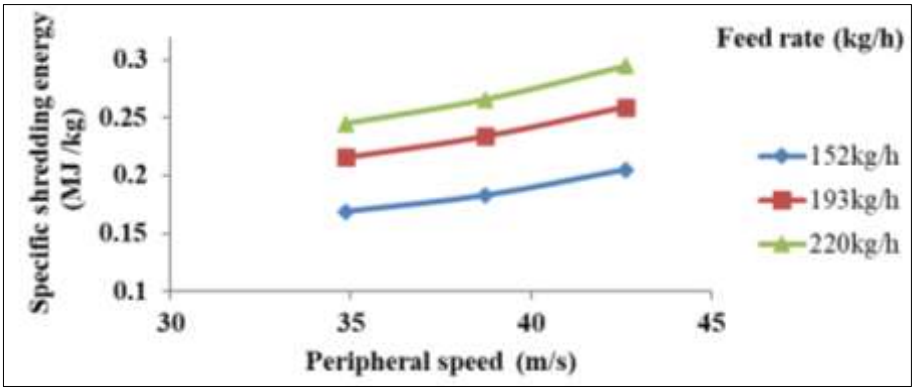

Fig 6: Effect of peripheral speed on specific shredding energy at different feed rate with 6 number of blades

Effect of number of blades, peripheral speed and feed rate on power requirement

The power requirement of cotton stalk shredder varied from 4.25 to 9.46 kW with different number of blades, peripheral speed and feed rate. The minimum power of 4.25 kW was recorded with 2 number of blades at 34. 88 m s^{-1} peripheral speed for 152 kg h^{-1} feed rate whereas the maximum power of 9.46 kW was found with 6 number of blades at42.63 m s^{-1} peripheral speed for 220 kg h^{-1} feed rate. The mean value of power requirement was found to be 6.39 kW.

The effects of different number of blades, peripheral speed and feed rate on power requirement are presented in Fig. 7, 8, 9. From the figures it was observed that power requirement of cotton stalk shredder increased with increase in number of blades, peripheral speed and feed rate. Power requirement was highest with 6 number of blades. Power requirement increased with increase in number of blades and peripheral speed due to more number of strokes per unit time. Power requirement increased with increase in feed rate due to high impact energy requirement. These results are in agreement with Alaa *et al.* (2016) [1] and Senthilkumar *et al.* (2010) [8].

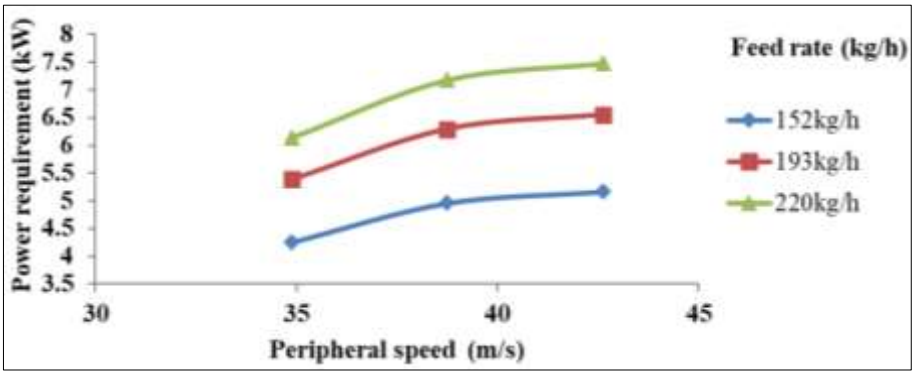

Fig 7: Effect of peripheral speed on power requirement at different feed rate with 2 number of blades

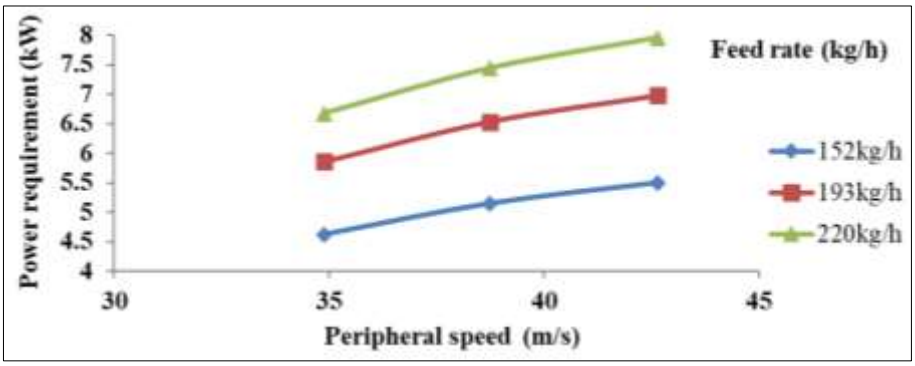

Fig 8: Effect of peripheral speed on power requirement at different feed rate with 3 number of blades

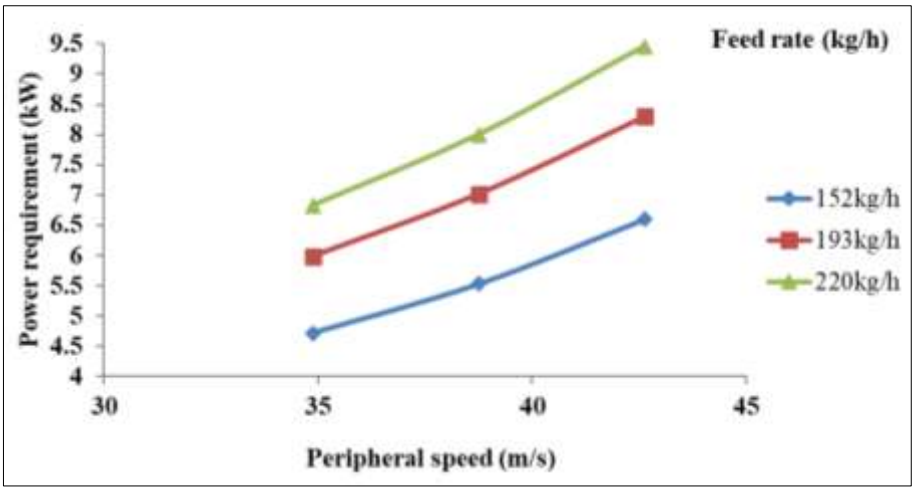

Fig 9: Effect of peripheral speed on power requirement at different feed rate with 6 number of blades

Optimization of machine and operational parameters of cotton stalk shredder

In order to improve the machine's performance and operational characteristics, studies were conducted to assess the cotton stalk shredder's performance in a lab setting *viz.*, number of blades, peripheral speed and feed rate. The performance parameters selected for the optimization process were length of cut, specific shredding energy and power requirement. The goal was set to minimize length of cut, power requirement and specific shredding energy.

Numerical optimization technique was used to optimize the operational parameters based on response constraints. The constraints used for the optimization process are given in Table 1. The optimization process was carried out using Design Expert software with CRBD method.

The numerical optimization was performed and the results are presented in Table 2. The operational parameters of cotton stalk shredder were optimized based on length of cut, power requirement and specific shredding energy. The best fit combination was found with a desirability of 0.90. This desirability was found with 6 number of blades at 152 kg h^{-1} feed rate for 34.88 m s^{-1} peripheral speed and for length of cut of 28 mm, power requirement of 4.72 kW, specific shredding energy 0.16 MJ kg^{-1}. The desirability graph is presented in Fig. 10.

Table 1: Multi response numerical optimization constraints for laboratory evaluation of cotton stalk shredder

Parameter	Goal	Lower	Upper	Importance
Number of blades	In range	2	6	3
Feed rate, kg h^{-1}	In range	152	220	3
Peripheral speed, m s^{-1}	In range	34.88	42.63	3
Length of cut, mm	Minimize	26	57	3
Specific shredding energy, MJ kg^{-1}	Minimize	0.144	0.295	3
Power requirement, kW	Minimize	4.25	9.46	3

Table 2: Optimized values for cotton stalk shredder based on number of blades, peripheral speed and feed rate

No of blades	Peripheral speed (m s^{-1})	Feed rate (kg h^{-1})	Length of cut (mm)	Power requirement (kW)	Specific shredding energy (MJ kg^{-1})	Desirability
6	34.88	152	28	4.72	0.164	0.90
3	34.88	152	33	4.62	0.160	0.87
3	34.88	193	35	5.86	0.162	0.80

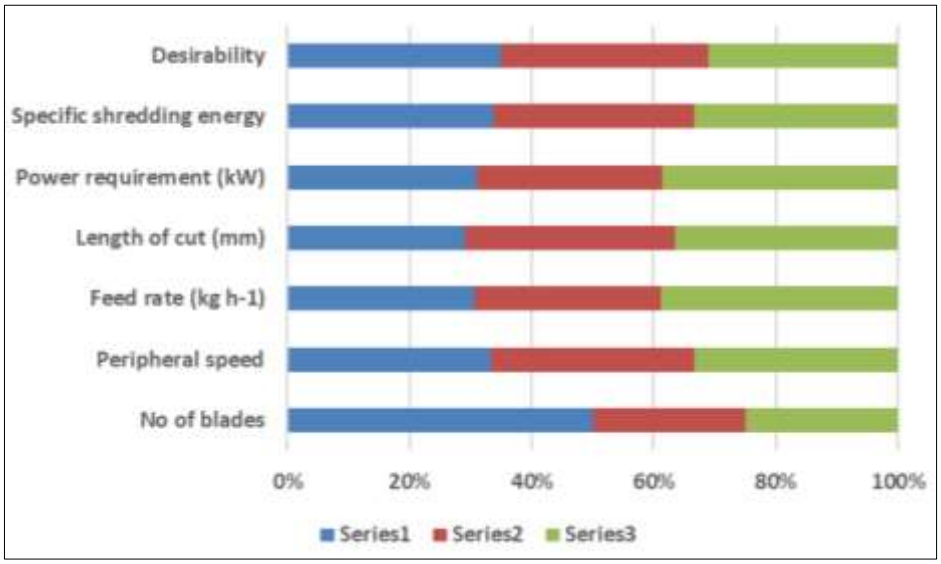

Fig 10: Desirability graph of cotton stalk shredder

Conclusions

Optimization of machine and operational parameters for the cotton stalk shredder is of paramount importance in achieving maximum efficiency during field operations. The minimum length of cotton stalk cut, measuring 26 mm, was attained at a peripheral speed of 42.63 m s-1, a feed rate of 152 kg h^{-1}, and with six blades. Furthermore, the minimum specific shredding energy of the cotton stalk shredder, which was recorded at 0.144 MJ kg^{-1}, was achieved at a peripheral speed of 34.88 m s-1, a feed rate of 152 kg h^{-1}, and with two blades. Additionally, the minimum power requirement of the cotton stalk shredder, which was recorded at 4.25 kW, was obtained at a peripheral speed of 34.88 m s-1, a feed rate of 152 kg h^{-1}, and with two blades. It was observed that the length of cut decreased with an increase in the number of blades, peripheral speed, and feed rate, while the power requirement and specific shredding energy increased.

Acknowledgements

No

References

1. Alaa AAA, Hassan MA, Afify MA, El-Shal HM. Performance evaluation of a local machine for cutting and chopping cotton stalks. Zagazig Journal of Agricultural Research. 2016;43(5):1735-1750.
2. Anonymous. Annual report on crop residues in India. Ministry of New and Renewable Energy; c2009. p. 138.
3. Anonymous. State-wise/year-wise area, production and yield in India. Cotton Advisory Board; c2018. p. 108.
4. Mehta H. Bioconversion of different wastes for energy options. Sardar Patel Renewable Energy Research Institute Vallabh Vidhyanagar; c2004, ppt.
5. Pathak BS. Crop residue to energy. In Environment and Agriculture, Chadha, K. L. and Swaminathan, M. S. (Eds.), Malhotra Publishing House, New Delhi; c2006. p. 854-869.
6. Pathak H, Bhatia A, Jain N, Aggarwal PK. Greenhouse Gas Emission and Mitigation in Indian Agriculture – A Review, In ING Bulletins on Regional Assessment of Reactive Nitrogen, Bulletin No. 19, (Ed. Bijay-Singh), SCON-ING, New Delhi; c2010. p. 1-34.
7. Patil VD, Narkhede NN, Deogirikar AA, Arulkar KP. Modifications and testing of rotavator for cotton shredding. New Agriculturist. 2004;15(2):9-12.
8. Senthilkumar T, Retired MR, Kathirvel K. Effect of blade and operational parameter on shredding efficiency of an experimental cotton stalk shredder. Agricultural Mechanization in Asia, Africa and Latin America. 2010;97(9):304-307.