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PERFORMANCE EVALUATION AND OPTIMIZATION OF A SUGARCANE PEELER-CUM-CUTTER MACHINE

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ABSTRACT

Sugarcane is multipurpose crop that serves as source of sugar, juices, jaggery and various products for man and raw materials for industry. But prior to the process of machining process, some processing is required to remove the solid particles, spots and sludge on the cane. The processing of sugarcane strips for industrial or human use involves different operations of which peeling is a major one and cannot be neglected. Also, due to increasing demand of sugarcane product and development of sugarcane industry a problem was found out that conservative peeling method of sugarcane would take times to cope with the increasing demand. Sugarcane Peeler cum cutter machine was designed and developed for peeling the sugarcanes and then cut it into pieces. Filler trials were conducted to determine optimum roller speed and roller clearance. Performance evaluation was carried out and different response parameters studied were peeling efficiency, machine output capacity and damage percentage. The machine output capacity of machine was found to be 90 Kg/h. At optimized conditions, peeling efficiency was found to be 58%. The damage percentage increased with increase in roller speed and decrease in clearance. At optimized conditions, cutting efficiency was found near 85%.

***Key words*: Sugarcane, Peeling, Peeling efficiency, Cutting efficiency, Output capacity.**

Introduction

Sugarcane (*Saccharum officinarum* L.) belongs to the family Poaceae and comprises more than 30 species and numerous cultivated hybrids developed through natural and human-assisted breeding (Moore *et al.*, 2014). It is a perennial tropical and subtropical grass that grows optimally in hot and humid climates, particularly in countries such as Brazil and India, which together account for a major share of global sugar production (FAO, 2023). The crop originated in Papua New Guinea and subsequently spread across Southeast Asia, India, the Mediterranean region, the Caribbean, and parts of the Americas through human migration and historical trade routes, resulting in extensive hybridization (Daniels & Roach, 1987). Sugarcane stalk juice is the primary source of nearly 70% of the world's sugar and is recognized for its exceptionally high caloric yield per unit area among cultivated crops (Solomon, 2011). Fresh sugarcane juice is widely consumed as a refreshing beverage in Asian countries such as India, China, Malaysia, and Thailand due to its pleasant taste, affordability, and nutritional value (Yusof *et al.*, 2000). In traditional Indian medicine systems, sugarcane juice has been employed in the treatment of jaundice and liver disorders (Singh *et al.*, 2015). Furthermore, sugarcane juice contains bioactive compounds such as flavonoids and phenolic substances that exhibit antioxidant activity and contribute to the prevention of degenerative diseases, including cardiovascular disorders and certain cancers (Kaur & Kapoor, 2001).

Despite its commercial potential, the large-scale marketing of fresh sugarcane juice is limited due to its rapid deterioration caused by microbial growth and enzymatic reactions (Prasad & Nath, 2002). Juice concentration and processing techniques have therefore been explored to extend shelf life, reduce storage and transportation costs, and improve product safety while maintaining sensory quality (Rao *et al.*, 2013). Sugarcane peeling constitutes a critical preprocessing step prior to juice extraction, following the removal of leaves. The stalk comprises an outer husk or rind, internal fibrous flesh, and juice-bearing tissues. Traditionally, peeling is performed manually using sharp knives, requiring substantial physical effort and posing safety hazards (Patil *et al.*, 2016). Manual operations are also constrained by labor shortages and low productivity, leading to increased processing time and costs. The development of mechanical sugarcane peeling machines has therefore gained attention as a means to enhance operational efficiency, reduce labor dependency, and improve economic returns for juice vendors and small-scale processors.

Materials and Method

Existing Machine

The sugarcane peeling cum cutting machine was designed and developed for the purpose of removal of hard surface of the sugarcane and to cut them into pieces. The sugarcane peeler cum cutter was installed on angle iron frame. It mainly consists of six rollers (three pairs). These rollers were connected to the rotating disk which has the adjustable slots by the roller pins. It has an arrangement of cutting for which a knife is attached to the machine. One motor is provided to operate the machine through belt drive. Details and dimensions of various components of the sugarcane peeler cum cutter are described.

Performance Evaluation

Sugarcanes were procured from local market of Akola and were used for peeling and cutting. Before start of actual experiments, preliminary trials were conducted and sugarcane peeler cum cutter machine was cleaned thoroughly. The sample of one sugarcane was used for each experiment. The sugarcanes were fed manually. After completion of peeling operation, the machine was stopped and different dimensions of peeled sample like weight, thickness were measured carefully. The performance of the sugarcane peeler was evaluated for its suitability for peeling of sugarcanes was tested with following parameters.

Table 1: Levels of independent variables for peeling of Sugarcane.

Independent variables	Symbols		Levels	
	Coded	Decoded	Coded	Decoded
Peeling Roller Speed, rpm	X_1	X_1	1	400
			0	300
			-1	200
Peeling Roller Clearance, mm	X_2	X_2	1	30
			0	25
			-1	20

Independent Variables

Following parameters were decided after conducting some filler trials.

1. Peeling Roller Speed, rpm - 200, 300, 400
2. Peeling Roller Clearance, mm - 20, 25, 30

Dependent Variables

1. Peeling Efficiency
2. Machine Output capacity

The peeling efficiency was assumed to be affected by peeling roller speed and peeling roller clearance. The levels of independent variables for peeling of sugarcanes are shown in Table 1. This table shows the coded and uncoded variables and their levels.

All the trials were conducted with 1 sugarcane sample size and data for peeling efficiency and machine output

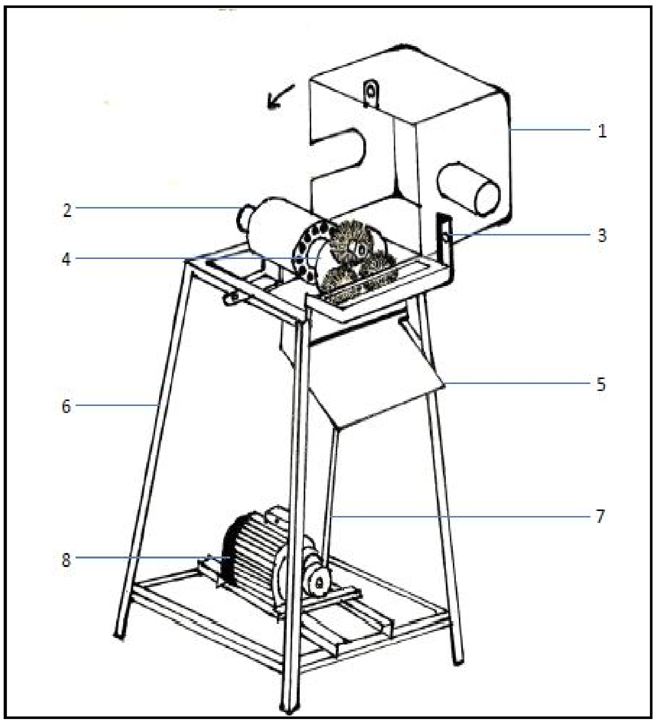

Fig. 1: Isometric View of Sugarcane Peeler cum Cutter Machine. [1. Cover; 2. Hollow Shaft; 3. Peeling Assembly; 4. Cutting Assembly; 5. Discharge unit; 6. Main Frame; 7. V-belt; 8. DC Motor].

Table 2: Effect of various levels of peeling parameters on peeling efficiency and Machine output Capacity.

Tr. No.	Roller speed, rpm	Clearance, mm	Peeling Efficiency, %	Machine Output Capacity, Kg/h	Damage Percentage, %
1	200	20	42.64	62.39	0.5
2	400	20	49.87	87.54	1.83
3	200	30	32	77.98	0
4	400	30	39.66	90.1	0
5	158.579	25	36.78	64.37	0
6	441.421	25	58.8	94.03	2.72
7	300	17.9289	45.96	62.96	2
8	300	32.0711	21.71	87.16	0
9	300	25	50.93	85	0
10	300	25	57.35	87.47	0.4
11	300	25	56.06	82.68	0
12	300	25	51.98	79.42	0.79
13	300	25	57.4	84.94	0

capacity was reported. To avoid bias, 13 runs were performed in a random order. The decision for the range and centre points of the variables was taken through preliminary trials.

Calculation of Machine Output Capacity

Machine output capacity was calculated by following expression, (Dehui, 2015)

Machine Output Capacity:

$$M.O.C. = \frac{M}{t}$$

Where,

M - Mass of sugarcane input, Kg

T - Time for peeling and cutting of sugarcane, h

Calculation of peeling efficiency

Peeling efficiency was calculated by following expression, (Afolabi and Attanda 2020)

Peeling Efficiency:

$$\eta = \frac{T_d}{T_i} \times 100$$

Where,

T_d -Thickness of sugarcane peeled by Machine, mm

T_i - ideal thickness to be peeled by machine, mm

Calculation of Damage Percentage

Damage percentage was calculated by following expression, (El-Yamani and Basiouny 2016)

Damage percentage:

$$Damage\ Percentage = \frac{W_D}{W_i} \times 100$$

Where,

Table 3: ANOVA for effect of treatment variables on machine output capacity.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1427.13	5	285.43	21.37	0.0004	significant
A-Roller speed	264.86	1	264.86	19.83	0.003	
B-Clearence	380.12	1	380.12	28.47	0.0011	
AB	0.0462	1	0.0462	0.0035	0.9547	
A²	81.34	1	81.34	6.09	0.043	
B²	751.98	1	751.98	56.31	0.0001	
Residual	93.48	7	13.35			
Lack of Fit	55.71	3	18.57	1.97	0.261	not significant
Pure Error	37.76	4	9.44			
Cor Total	1520.61	12				

Std. Dev.	3.65	R^2	0.9385
Mean	46.24	Adjusted R^2	0.8946
C.V. %	7.90	Predicted R^2	0.7007
		Adeq. Precision	12.8255

W_D – Weight of the damage sugarcane, g

W_i – Initial weight of the sugarcane, g

Result and Discussion

Performance Evaluation

The experiments were conducted with various treatment Table 2 shows effect of various levels of peeling parameters on peeling efficiency. The peeling efficiency was observed to be ranging between to 21.71 to 58.8%. The maximum peeling efficiency of 58.8% was observed at 441 rpm roller speed and 25 mm roller clearance but the damage percentage was also high.

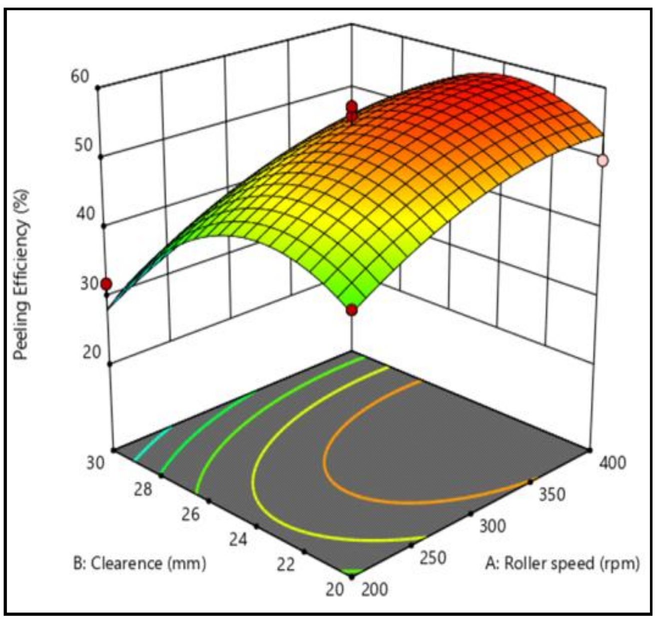

Fig. 2: Effect of roller speed and roller clearance on Peeling Efficiency.

Table 4: ANOVA for effect of treatment variables on machine output capacity.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1282.85	5	256.57	21.67	0.0004	significant
A-Roller speed	784.39	1	784.39	66.25	< 0.0001	
B-Clearence	342.88	1	342.88	28.96	0.001	
AB	42.45	1	42.45	3.58	0.1002	
A²	21.5	1	21.5	1.82	0.2198	
B²	101.93	1	101.93	8.61	0.0219	
Residual	82.88	7	11.84			
Lack of Fit	46.29	3	15.43	1.69	0.3062	not significant
Pure Error	36.6	4	9.15			
Cor Total	1365.74	12				

Std. Dev.	3.44	R²	0.9393
Mean	80.46	Adjusted R²	0.8960
C.V. %	4.28	Predicted R²	0.7171
		Adeq Precision	15.3056

This happened due to the increase in roller speed which increases the contact time of wire brush with the sugarcane. But at the same roller speed, there is high percentage of damaged sugarcanes. The minimum peeling efficiency of 21.71% was observed 300 rpm roller speed and 32.07 mm roller clearance. Due to the high clearance in rollers, the sugarcane did not get uniform contact with the wire brush. similar results found by (Fadeyibi and Ajao, 2020).

The results showed that among linear effects roller clearance had significant effect on peeling efficiency ($P<0.05$) at 5 % level of significance followed by roller speed. The existence of quadratic terms indicates the curvy linear nature of response. It indicates that increasing the value of roller clearance initially increases the response up to certain level of variable however further increase in the level of variable decreases the value of response. On the other hand, as the increase in the value of roller speed, the peeling efficiency increases but the breakages also increased (Temam, 2017).

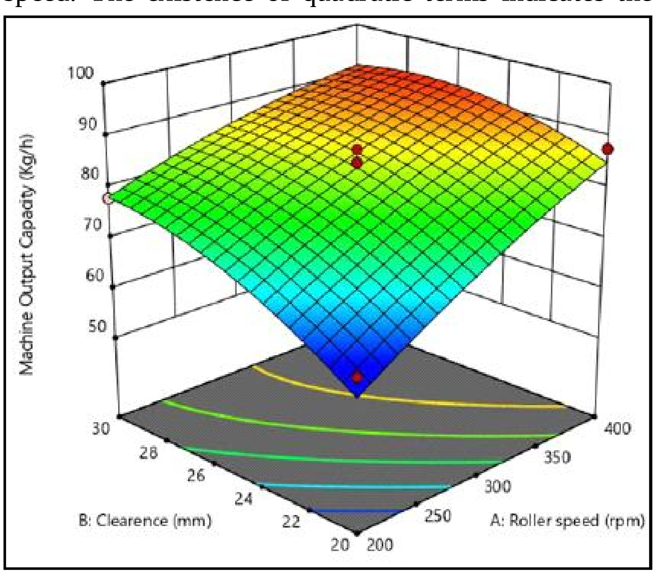

Fig. 3: Effect of roller speed and roller clearance on machine output capacity.

The quadratic response surface model data indicated the results as significant. The lack of fit was found to be non-significant which indicates that the developed model was adequate for predicting the response. The coefficient of determination (R^2) was 0.9385 for peeling treatment which indicated that the model could fit the data for peeling activity very well for both the variables, i.e. roller speed and roller clearance.

From Table 2, the machine output capacity was observed to be ranging from 62.39 Kg/h to 94.03 Kg/h depending upon the treatments. The maximum machine output capacity was observed in case of treatment having the combination of roller speed 441 rpm and 25 mm roller clearance. This was happened because, high roller speed increases the speed of operation and less time required for peeling. The minimum machine output capacity was found for treatment having the combination of roller speed 200 rpm and roller clearance 20 mm. At this roller speed and roller clearance the time required was greater because, less clearance choke the process and less roller speed was responsible for the difficulties in forward movement of the sugarcane (El-Yamani and Basiouny, 2016).

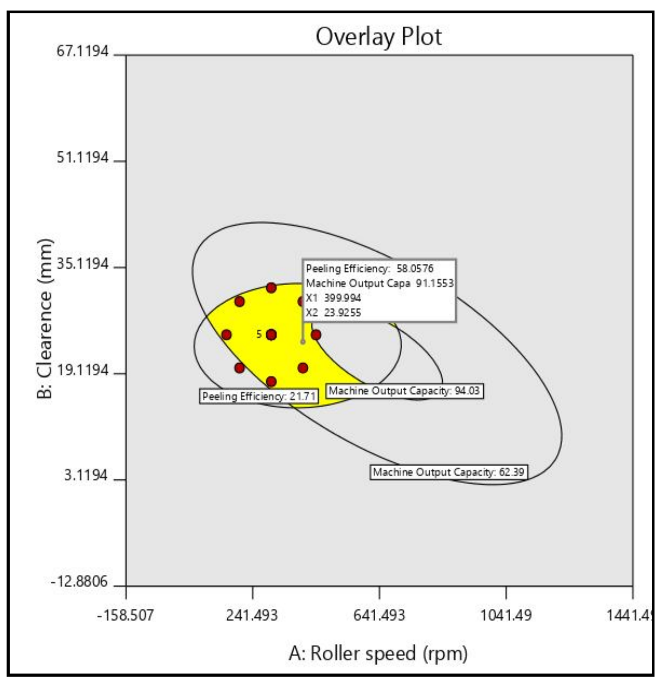

Fig. 4: Superimposed contours for peeling efficiency and Machine output capacity.

Table 5: The optimization criteria for different input parameters.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Roller speed	is in range	200	400	1	1	3
B:Clearence	is in range	20	30	1	1	3
Peeling Efficiency	Maximize	21.71	58.8	1	1	3
Machine Output Capacity	None	62.39	94.03	1	1	3

The ANOVA in Table 4 revealed that the model was highly significant at 1% level of significance. The results showed that among linear effects, roller clearance was more effective on machine output capacity followed by roller speed. All the interaction and quadratic effects were found significant for machine output capacity. The lack of fit was non-significant and hence the model can be considered as quite adequate for predicting the response. The coefficient of determination (R^2) was 0.9393 for machine output capacity which indicated that the model could fit the data for activity very well for both the variables, i.e. roller speed and roller clearance.

Optimization of peeling efficiency and machine output capacity

Numerical optimization:

In order to optimize the input parameters for sugarcanes by numerical optimization this finds a point that maximizes the desirability function. The main criteria for optimization were maximum peeling efficiency, maximum machine output capacity and all the input parameters in range. The optimization criteria for different input parameters and responses constraints are as shown in Table 5.

Software generated optimum conditions of independent variables with the predicted values of responses is as below. Software Design Expert version 11 was used for the optimization of responses. A stationary point at which the slope of the response surface was zero in all the direction was calculated by partially differentiating the model with respect to each variable, equating these derivatives to zero and simultaneously solving the resulting equations. The optimum values for different variables and their predicted responses thus obtained are given in Table 6.

Table 6: The optimum values for different variables and their predicted responses.

Variable	Optimized values	Responses	Predicted values
Roller Speed, rpm	399.994	Peeling efficiency, %	58.059
Roller clearance, mm	23.926	Machine output capacity, Kg/h	91.155
Desirability	0.94		

Graphical optimization:

The superimposed contours for response and their intersection for maximum peeling efficiency Fig. 4 indicated the range of optimum values of process variables. The superimposed contours of both the responses for both variables along with their intersection zones for maximum peeling efficiency (%), maximum machine output capacity, indicated the range of optimum values of process variables.

Damage Percentage (%):

The results of damage percentage by using various peeling parameters are given in Fig. 5.

Cutting Efficiency:

After peeling, sugarcanes were evaluated for the cutting efficiency at 400 rpm roller speed, 24 mm roller clearance. The average cutting efficiency was found to be 85.44%. The Fig. 6 shows that there was not too much variation in cutting efficiency and its range was 83-88%. A graph showing variation in cutting efficiency is given in Fig. 6.

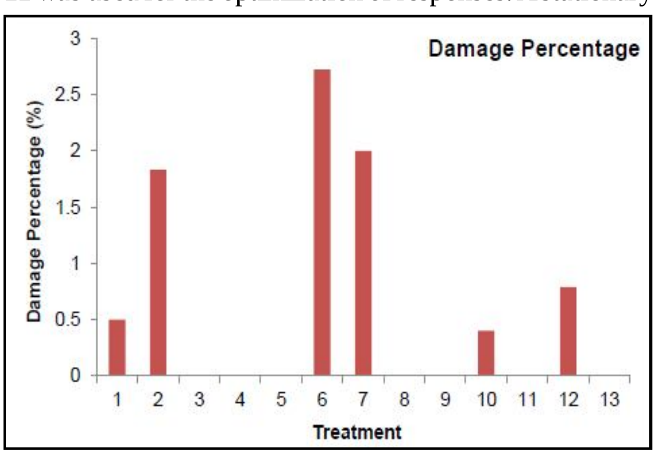

Fig. 5: Damage Percentage.

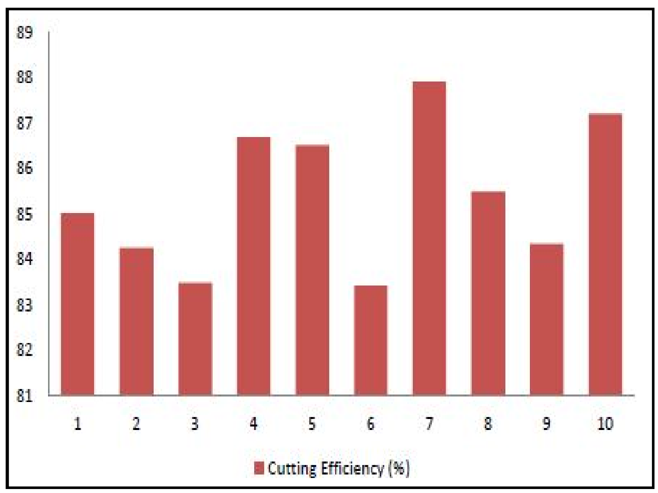

Fig. 6: Variation in cutting efficiency.

Conclusion

The performance evaluation of the developed sugarcane peeler cum cutter demonstrated satisfactory operational efficiency and economic feasibility. The machine exhibited a processing capacity of approximately 90 kg h^{-1} under optimized working conditions. The highest peeling efficiency of 58.8% was achieved at a roller speed of 441 rpm combined with a roller clearance of 25 mm, indicating the significant influence of these parameters on peeling performance. Furthermore, the cutting unit recorded a maximum cutting efficiency of 87.9%, confirming its effectiveness in producing uniformly cut sugarcane pieces. Economic analysis revealed a favorable cost–benefit ratio of 1.95, along with a break-even point of 43.86%, suggesting that the machine is economically viable and suitable for adoption by small- and medium-scale sugarcane processors.

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