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Design, fabrication and performance evaluation of tractor operated sugarcane leaf stripper for labour saving and cost reduction machinery in sugarcane

Anurag Patel, Sheen Cline Moses, Prashant MD'Souza and Rana N Alam

Abstract
The manual harvesting of sugarcane, only the removal of tops and leaves takes a major portion of the total time for harvesting. The conventional process of burning the tops results in the loss of biomass which could have been useful for other trash farming and source of energy. Also, the harvesting process causes drudgery and losses to the cultivators as of the labor shortage. The delay in harvesting affects the quality of the crop, the developed tractor-operated sugarcane leaf stripping machine is designed and fabricated by keeping in mind the need for a mechanized solution in especially in the harvesting process of sugarcane. The main components of the machine are the intake roller, blower unit, leaf stripping unit and power transmission system and tractor. The machine was tested on three varieties of sugarcane; MCO-238, K-269 and R-94184. The maximum leaf stripping efficiency for MCO-238, K-269 and R-94184 was obtained to be 87.27%, 86.59% and 87.50% respectively and the maximum damage on stalk was reported to be 5.25%, 5.32% and 7.19% respectively. The percentage reduction in cost is 58.23% as the cost reduced from Rs. 800 in manual mode to Rs. 334.26 in mechanised mode.

Keywords: Design, fabrication, performance evaluation, tractor operated, sugarcane

Introduction
Sugarcane crop belongs to the *Saccharum sensu stricto*, the genus is contains the higher order polyploidy species (>4x). The family of sugarcane is Graminease, class monocotyledons, sub family panicoidae, genus *Saccharum* and tribe *Andropogoneae*. Sugarcane is native to the wide range of region from warm temperate to tropical regions of South Asia and Melanesia. (Anjaneyulu, *et al.*, 2018) [1].
Cultivation of sugarcane in India dates back to Vedic period, the earliest mention of sugarcane can be found in Indian ancient text from 1400 BC to 1000 BC. The early production of sugar production in Indian subcontinent has been reported in the ancient Sanskrit and Pali texts. The known earliest production is of crystalline sugar form sugarcane began in North India. Different species of sugarcane originated at different locations, with *S. edule* and *S. officinarum* having origin in New Guinea and *Saccharum barberi* being native to India. (Department of Agriculture & Cooperation and Farmers Welfare, 2021) [8].
India is second after Brazil in sugarcane production, for 2020-21 around 48.57 lakh hectare land was under sugarcane production in India which is expected to go around 54.55 lakh hectares in 2021-22. Uttar Pradesh and Maharashtra are leading cultivating states in India with 21.80 lakh hectares and 11.43 lakh hectares land under cultivation (2020-21 data). (DAC, 2021) [7].

Sugarcane mechanization status in India
As of the 2016-17 data regarding farm power availability in India, 2.24 $kWha^{-1}$ total farm power was available with 1.324 $kWha^{-1}$ share of tractor, 0.018 $kWha^{-1}$ share of power tiller, 0.021 $kWha^{-1}$ share of combine harvester, 0.460 $kWha^{-1}$ share of diesel engine, 0.193 $kWha^{-1}$ share of electric motor, 0.091 $kWha^{-1}$ share of humans and 0.130 $kWha^{-1}$ share of draught animals. The overall increase in mechanization of sugarcane was seen to be 24%. The increase in mechanization trends are also supported by efforts made by government in establishment of custom hiring centres, high tech machinery hubs and farm machinery banks availability in village areas to support the field operation of small and marginal farmers. (Mehta, *et al.*, 2019) [15].

Government of India has given special consideration to increase farm mechanization in the country, a special scheme “Sub Mission on Agricultural Mechanization (SMAM)” was launched in 2015-16. The aim of scheme is to “reach the unreached”, by making advance mechanized machinery available to small and marginal farmers (SMFs). As of the initiation and support by government through various scheme the availability of total farm power increased from 2.02 $kWha^{-1}$ in 2016-17 to 2.49 $kWha^{-1}$ in 2018-19. (PIB, GoI, Ministry of Agriculture & Farmers Welfare, 2021) [17].

Uttar Pradesh is the leading producer of sugarcane in the country with contribution of around 43.65% of total land under cultivation and 35.21% of total sugarcane production in India. Most of the process consumes lots of time when done manually (375 man-days/ha) and involves lots of drudgery resulting in increase of input cost and reduction in the profit percentage. In sugarcane production the mechanization is mostly limited to process like land preparation and to extent to planting and intercultural operations. Stills there is lot to do in providing mechanization in harvesting of sugarcane as it is the most labor consuming operation (Singh, *et al*., 2016) [20].

Sugarcane cultivation is labor consuming process which requires around 3300 man working hours during its duration for different operations. Use of harvesting knife is among the most common manual harvesting techniques being followed in India, manual harvesting is very time consuming and costly as it takes around 850-1000 man working hours per hectare when sugarcane is harvested manually (Kishore, *et al*., 2017) [11].

Recent research and developments in harvesting of sugarcane through mechanized

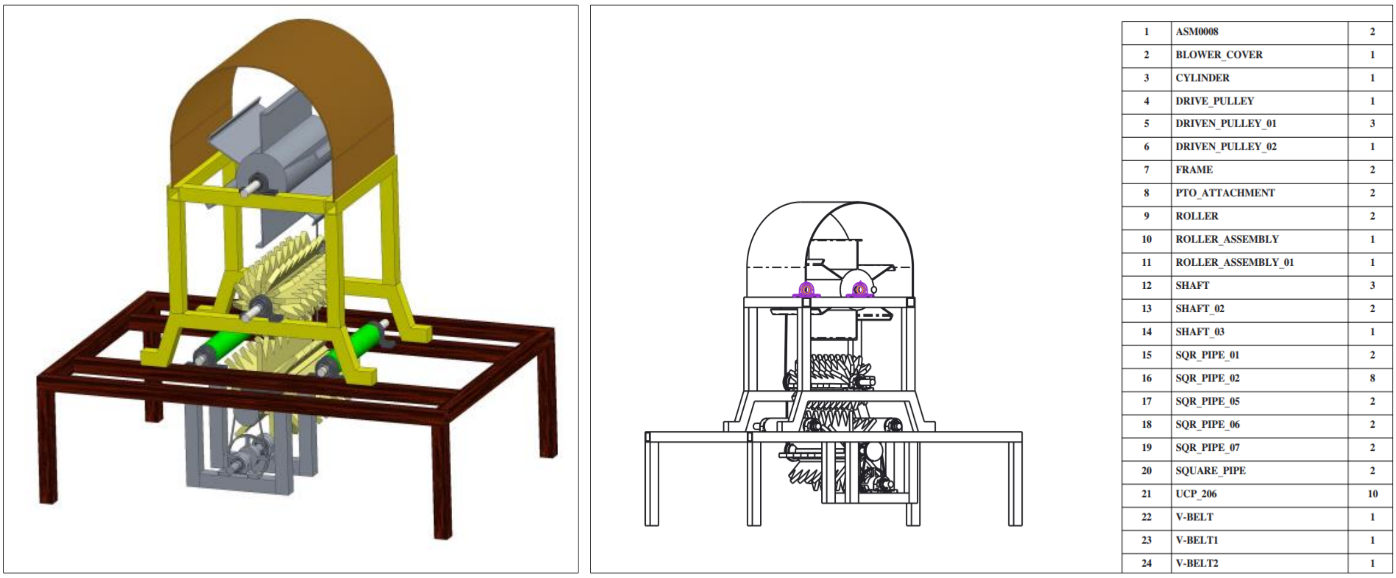
Cansee Sopa, 2018, conducted a study with title “A study of Sugarcane Leaf-Removal during Harvest”, the aim of the study is to establish the role of mechanization in harvesting of sugarcane with reduction in contamination and less time in harvesting. LK92-11 variety of sugarcane having 12 months of harvesting period, 9,387 stems/rai density and can produce 1675.2 kg/rai leaves, 180 kg/rai sheath and up to 14.01 tonns/rai of sugarcane tops. When mechanized means were employed in harvesting, the reduction in leaf removal time significantly reduced from 37 h/rai to 11.4h/rai. (Cansee, 2010) [6].

In a study where large scale sugarcane leaf stripper was introduced with automatic feed, it was found that with advances in harvesting technique where stripper wheels having leaf stripping bars installed in them are used can reduce the labor intensity without compromising the quality and could prove helpful in using the removed leaves from recycling or reuse point of view. (Lin, *et al*., 2012) [13].

Sing & Solomon, 2014 [19], conducted a study “Development of a Sugarcane Detrasher”, the results of study focused on economic benefits of mechanisation in sugarcane harvesting. It was evaluated that with use of powered operated detrasher on CoPant 97222, CoLk 97147, CoSe 95422, CoLk 84184 and LG 96115, the cost per ton of cane reduced from INR 100 to INR 83. Overall there is reduction of 17% in operation cost and 84% in labor requirements (Singh & Solomon, 2014) [19].

Materials and Methods

Keeping in view the benefits of mechanized harvesting solution and need of mechanized means especially in sugarcane leaf stripping a tractor power sugarcane leaf stripping machine is designed and fabricated at Division of Farm Machinery and Power Engineering, Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agricultural Technology and Sciences, Prayagraj District of Uttar Pradesh. The machine is operated by 3 skilled persons and has output of 2 tons per hour. The aim of machine is to provide efficient and economical solution to local cultivators of sugarcane.



1	ASM0008	2
2	BLOWER_COVER	1
3	CYLINDER	1
4	DRIVE_PULLEY	1
5	DRIVEN_PULLEY_01	3
6	DRIVEN_PULLEY_02	1
7	FRAME	2
8	PTO_ATTACHMENT	2
9	ROLLER	2
10	ROLLER_ASSEMBLY	1
11	ROLLER_ASSEMBLY_01	1
12	SHAFT	3
13	SHAFT_02	2
14	SHAFT_03	1
15	SQR_PIPE_01	2
16	SQR_PIPE_02	8
17	SQR_PIPE_05	2
18	SQR_PIPE_06	2
19	SQR_PIPE_07	2
20	SQUARE_PIPE	2
21	UCP_206	10
22	V-BELT	1
23	V-BELT1	1
24	V-BELT2	1

Fig 1: CAD drawing of development of sugarcane stripper

Main components of PTO operated sugarcane stripper

1. Main Frame: Main frame of the machine is designed and developed as per required strength and space. The size of main frame is made of mild steel (MS) angle of size 25×25×5 mm. The strength of main frame is optimal to support the assembly parts and to absorb the vibration produced during operation. Overall dimension of main frame are 1100×1600×460 mm.

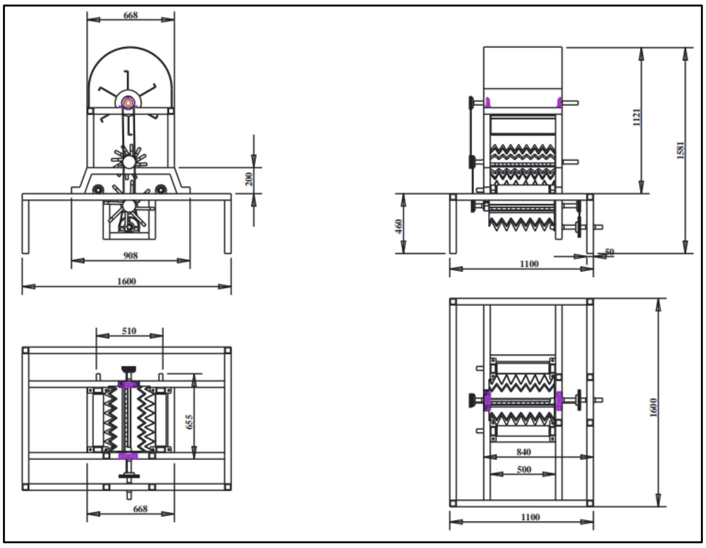
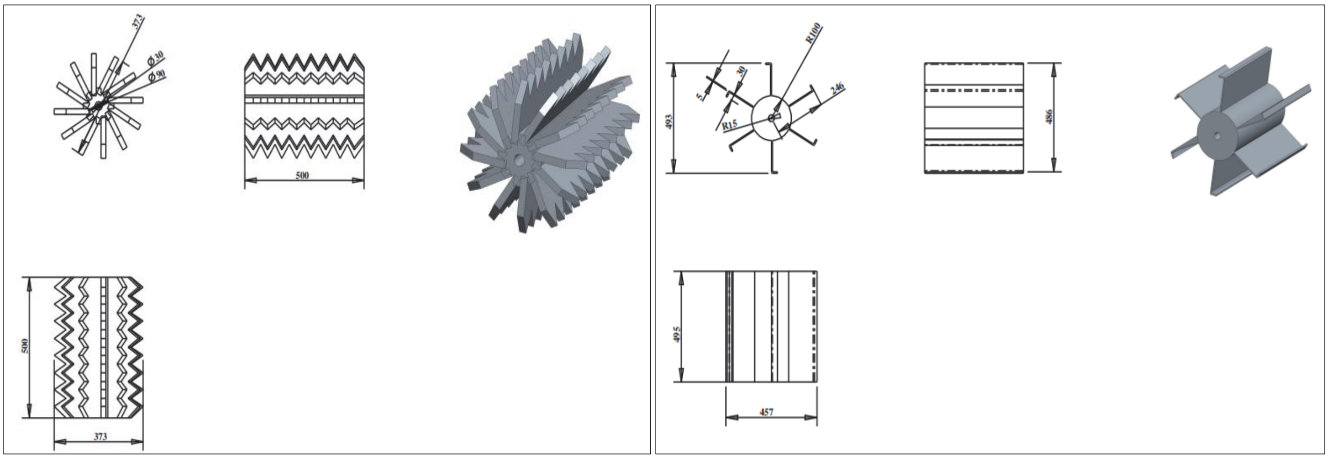


Fig 2: Overall dimension of sugarcane stripper

2. Feeding chute: The feed chute is ergonomically designed and fabricated of mild steel sheet of 5 mm. Feeding chute is provided on the machine at 10° angle from horizontal.

3. Intake and out roller unit: Two roller mild steel (MS) are provided in combination which are placed at entry and exit point of the cleaning unit. Supporting rollers have function to support and slide the sugarcane stalk in to the stripping unit.

4. Stripping roller and Air Blower Assembly



(A) **(B)**

Fig 3: (a) Leaf stripping roller and (b) Air blower of sugarcane stripper

The design of the roller is provided below:

$$\sigma = \frac{3F_{cr}L}{4bd^2} \qquad (1)$$

Equation 1 is used to calculate the minimum thickness of the bar to prevent the bending of bar during operation. σ is the bending strength of roller i.e. 1.6 x 108 N/m^2, L represent length of MS bar on roller i.e. 90 cm, b represent roller bar width i.e. 1.95 cm, and F_{cr} represents the crushing strength of sugarcane which is taken to be 1.53 Kn (Bastian & Shridara, 2014) [4].
As per the formula the calculated thickness (d) of the roller bar is evaluated. Angular velocity for designing and parameter setting of roller assembly is for roller radius of 18.65 cm and linear velocity of 260 cm/s is derived from the equation (2) given below (Li & Zhou., July 2013) [12]:

$$w = \frac{v}{r} \qquad (2)$$

w = angular velocity
$v = Linar\ velocity, \frac{cm}{s}$
r= radius of roller, cm

The required angular velocity came out to be 286 cm/s. The revolution of the roller required to achieve the required angular velocity is derived from the equation (3) below (Gbabo, *et al.*, October, 2013) [9]:

$$N = \frac{\omega \times 60}{2\Pi} \qquad (3)$$

The circumference (C) of the blower roller was calculated through equation 4 and came out to be 80 cm.

$$C = 2\Pi r \qquad (4)$$

In designing of the sugarcane leaf stripper the crushing strength of the sugarcane stalk is taken to be 750 N and tensile strength of the leaf sheath is taken as 92 N as suggested by

(Sandhar, *et al.*, 2001) [18]. It means to remove sheath the force greater than 92 N is required and the crushing force from the roller should be below 750 N in order to prevent the sugarcane stalk from possible damage from the roller. In designing the spring loaded roller, less than half of the crushing strength is taken i.e. below 325 N (Magalhaes, *et al.*, 2005) [14]. Material of the spring is taken as music wire and the design procedure is as per the procedure followed and equations given in experimental study by (Budynas & Nisbett., 2006) [5].
The ultimate tensile strength is calculated from the equation (5):

$$S_{ut} = \frac{A}{d_w^m} \quad (5)$$

Where, A and m are constants with value 2211MPa and 0.145 respectively (Ikram, *et al.*, 2019) [10] and spring diameter d_w is taken a 0.5 cm.
Further, in designing of the spring assembly for roller, the spring index (C_s), Solid length (L_s) and Number of active coils (N_a), are calculated from the equation (6), (7), (8) & (9) given below:

$$C_s = \frac{2\alpha-\beta}{4\beta} + \sqrt{(\frac{2\alpha-\beta}{4\beta})^2 - \frac{3\alpha}{4\beta}} \quad (6)$$

Here, α&β are constants and spring index came as 5.57.
Mean diameter of the spring coil (D) is calculated from

$$D = C_s \times D_s \quad (7)$$

$$N_a = \frac{Gd^4}{8kD^3} \quad (8)$$

$$L_s = N_a \times D_s \quad (9)$$

Free length of the spring 70 mm.
Weight of the spring 120 gram
The roller shaft diameter which is for the rotation of roller is derived from the equation 10 below (Ashraf, *et al.*, 2007) [3]:

$$d = 3\sqrt{\frac{16\tau}{\pi S_s}} \quad (10)$$

Where, d is the diameter, τ is the torque (kg-cm), S_s is safe shear stress (Kg/cm^2).
The shaft is material is cast iron and safe operating diameter of the shaft is taken as …..cm.

5. Cleaning element: It is a portion the machine where the leaf from the stalk is removed, the surface material of the cleaning element is of prime importance. During leaf cleaning procedure the cleaning element is subjected to periodic dynamic loads and in condition where deformation can be formed. There are many factors that affect the cleaning element like material, speed, structure and surface of the cleaning element (Meng, *et al.*, 2009) [16]. As the leaf removal process includes the force of friction between cleaning element and sugarcane stalk therefore nylon rubber is provided on the cleaning element so to minimize the damage on stalk and easy removal of the leaf from the stalk.

6. PTO attachment: PTO attached arrangement is provided on the back side sugar cane stripper machine for easy operation of machine through tractor. Air Blower: Air blower is placed above the stripping unit. It function is to blow away the leaves removed by stripping roller.

Experimental procedure
In the experimental study to analyse the leaf stripping performance of designed and developed tractor operated leaf stripper three varieties of sugarcane are selected; a. MCO-238, b. K-269, c. R-94184. The machine was run at (250-300) RPM of the roller and (300-350) RPM of blower to produce air velocity of 23.6 m/s. The stripping efficiency of the machines for each experiment is calculated by equation 11 (Bastian & Shridara, 2014) [4].

$$\eta_d = \frac{W_1-W_2}{W_1-W_3} \quad (11)$$

Where, $W_1$is mass of de-topped cane, $W_2$is mass of de-trashed cane and $W_3$is mass of clean cane.

Cost of operation of machine
A) Fixed cost of machine
Depreciation
This cost reflects the reduction in value of a machine over time during operations. The depreciation cost was calculated using formula based on straight line method. (Patel, *et al.*, 2020) [2].

$$D = \frac{P-S}{L} \quad (12)$$

Where, D = depreciation cost, average per hours, P = purchase price of machine, S = salvage value of the machine, L = life of machine in working hour = l x h, l = useful life in year, h = working hour per year.

Interest
Annual charge of interest was calculated on the basis of actual rate of interest payable and average purchase price by the following equation (13)

$$\text{Intrest} = \frac{P+S}{2} \times \frac{i}{100} \times \frac{l}{h} \quad (13)$$

Where,
i = rate of interest.

Housing
It was calculate on the basis of 1.5 percent of the average purchase price of the machine as per the equation (14).

$$\text{Housing} = \frac{P+S}{2} \times \frac{H}{100} \times \frac{l}{h} \quad (14)$$

Where,
H = rate of housing, percent per year.

Insurance and taxes
It is the actual amount paid or to be paid annually for insurance and taxes. It was calculated on the basis of the 2 percent of average price using equation (15)

$$\text{Insurance and taxes} = \frac{P+S}{2} \times \frac{I}{100} \times \frac{l}{h} \quad (15)$$

Where,
I = rate of insurance and taxes, percent per year.

B) Variable cost of machine

Repair and maintenance

Actual expenses will increase with years of use of the machine. However, to simplify the calculation, the method of average repair and maintenance expense per year is adopted and repair and maintenance cost was calculated by using equation (16).

$$\text{Repair} = P \times \frac{R}{100} \times \frac{l}{h} \quad (16)$$

Where, R = rate of repair and maintenance, percent per year.

Lubrication cost

Charges for lubricant are to be calculated on the actual consumption, but in present study analysis the lubricants cost were taken between 30 to 35% of the fuel cost.

Labour cost

The labour cost per hour was calculated as per local labor rates on the 8 of hours of work per day.

Result and Discussion

The data regarding the stripping rate and percentage damage to stalk in given below:

Table 1: MCO-238 output results

Trial No.	De-topping time, s	Stripping rate, kgh^{-1}	Damage to stalk, %	Stripping efficiency, %
1.	2.50	1825	4.19	82.95
2.	2.52	1860	4.85	84.55
3.	2.55	1870	5.65	85.00
4.	2.56	1865	4.25	84.77
5.	2.58	1875	4.95	85.23
6.	2.55	1885	5.10	85.68
7.	2.61	1880	4.70	85.45
8.	2.58	1900	4.80	86.36
9.	2.60	1920	5.35	87.27

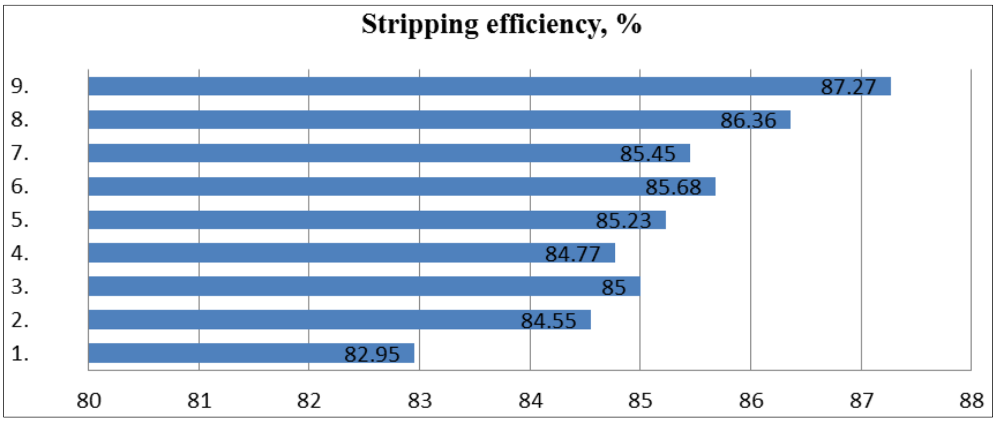


Fig 4: Stripping efficiency of MCO-238

Table 2: K-269 output results

Trial No.	De-topping time, s	Stripping rate, kgh^{-1}	Damage to stalk, %	Stripping efficiency,%
1.	2.42	1835	4.22	83.41
2.	2.49	1855	4.75	84.32
3.	2.53	1865	5.57	84.77
4.	2.53	1866	4.37	84.82
5.	2.57	1876	4.97	85.27
6.	2.51	1883	5.15	85.59
7.	2.6	1885	4.79	85.68
8.	2.54	1897	4.83	86.23
9.	2.57	1905	5.32	86.59

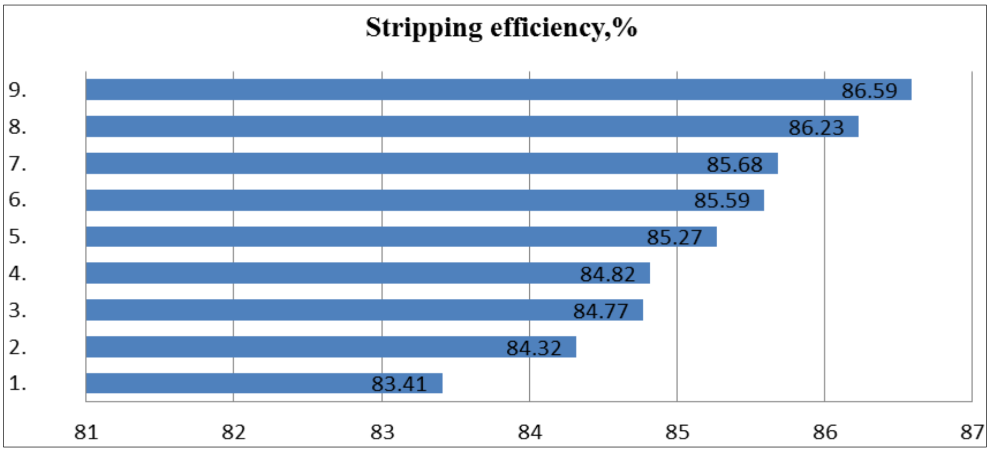


Fig 5: Stripping efficiency of K-269

Table 3: R-94184 output results

Trial No.	De-topping time, s	Stripping rate, kgh^{-1}	Damage to stalk, %	Stripping efficiency,%
1.	2.47	1855	5.61	84.32
2.	2.50	1870	6.23	85.00
3.	2.54	1882	7.21	85.55
4.	2.62	1875	5.95	85.23
5.	2.67	1890	6.52	85.91
6.	2.57	1895	7.12	86.14
7.	2.71	1887	6.05	85.77
8.	2.67	1905	6.15	86.59
9.	2.66	1925	7.19	87.50

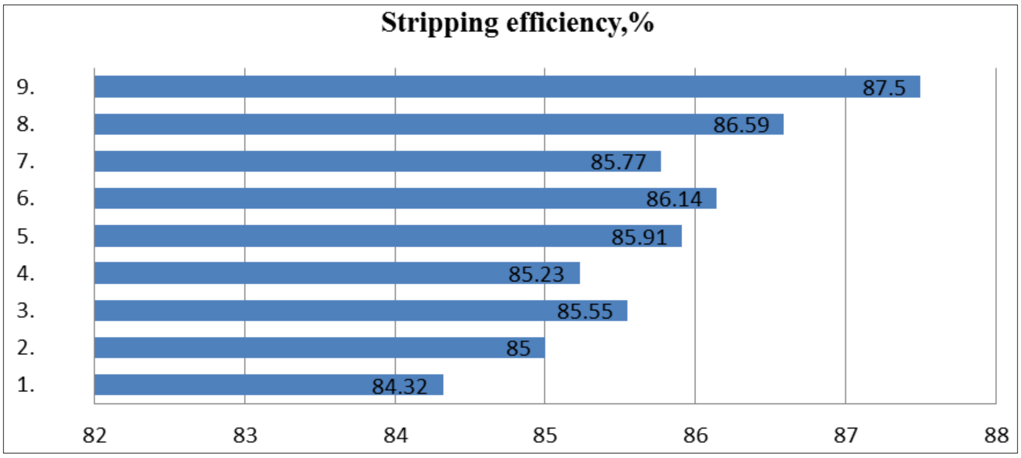


Fig 6: Stripping efficiency of R-94184

The machines successfully performed the stripping process without damaging the stalk of cane, the highest stripping efficiency for MCO-238 was achieved to be 87.27% with only 5.25% damage to stalk. Similarly for K-269 and R-94184, the highest stripping efficiency were calculated to be 86.59% and 87.50% respectively and for damage to stalk for cane was reported to be 5.32% and 7.19% respectively. As the feed rate increases the damage to stalk also increase, the feed rate is important factor in deciding the stripping rate and stripping efficiency. The effect of sugarcane variety on sugarcane stripping efficiency was not as significant as comparable efficiencies are calculated.

Table 4: Cost estimation of mechanical sugarcane leaf stripping

Estimation of machine cost	Machine price INR	Fixed cost, Rs./ h	Variable cost, Rs./ h	Total cost, Rs./ h
Tractor: New Holland 35 hp.	5,50,000	90.75	456.6	547.35
Machine: Sugarcane leaf stripper	35,000	24.06	57.00	81.06
Total cost	5,85,000	114.81	513.6	628.4125

Initial capital of the tractor operated sugarcane leaf stripper machine is INR 5, 85,000/- (including the cost of tractor, the total cost per hour came out to be INR 628.4125 per hour of operation. The cost of operation of machine is given in table 4. The total sugarcane leaf stripping cost in mechanical was Rs. 628.41 per hours and average sugarcane stripping rate is 1.88 ton per hour. The cost of sugarcane leaf stripping by machine came out to be Rs. 334.26 per ton. On the other hand he manual sugarcane leaf stripping includes labour cost for stripping operation. The manual sugarcane leaf stripping labour cost to cover one hectare in field was Rs. 16,000. The manual sugarcane leaf stripping cost was Rs. 800 per ton. Hence, there is 58.23% decrease in cost of sugarcane leaf stripping when mechanical means are applied.

Conclusion

As the growing concern for shortage in labour especially during the harvesting season the mechanized solution for stripping of sugarcane leafs will help the cultivators and prevent the losses and drudgery during the harvesting. The tractor operated leaf stripper machines is designed and fabricated and then tested for stripping efficiency. The machines was run at 200-250 rpm of roller and 300 rpm of blower, the leaf stripping was performed on three varieties of sugarcane; MCO-238, K-269 and R-94184. The maximum leaf stripping efficiency for MCO-238, K-269 and R-94184 was obtained to be 87.27%, 86.59% and 87.50% respectively. For the same operation the average cost of operation per hour came out to be INR 628.4125. The cost reduction due to mechanised sugarcane leaf stripping per ton reduced from Rs. 800 in manual mode to Rs. 334.26 in mechanised mode, the total percentage reduction in cost is 58.23%. The damage done to the stalk was in permissible limit.

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