

## DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF INDIGENOUS SUGARCANE LEAF STRIPPING MACHINE

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Sugarcane trash (leaves + tops) removal takes 65% time of manual harvesting. Conventional trash burning in standing crop wastes all biomass material which can be used for trash farming and as a source of renewable energy to mitigate natural resources and energy crisis. Shortage of skilled labour and machinery for leaf removal during peak harvesting season causes late harvesting and about 10% deduction in selling price. A small sugarcane leaf stripping machine was designed and fabricated to deduce these problems. Main components of stripping machine were intake rollers, cleaning element, out take rollers, power transmission system and an engine as power source. Three combinations for intake rollers were fabricated. Three velocities i.e., CE<sub>1</sub> (660 rpm), CE<sub>2</sub> (763 rpm) and CE<sub>3</sub> (1033 rpm) of cleaning element, two level of sugarcane leaf moisture content, M.C<sub>1</sub> (8.2%) and M.C<sub>2</sub> (17.60%) and three sugarcane varieties, V<sub>1</sub> (US-658), V<sub>2</sub> (HSF-240) and V<sub>3</sub> (CPF-249) were selected for machine performance evaluation. The results indicated that Inlet roller combination C<sub>3</sub>, cleaning element speed CE<sub>3</sub>, sugarcane crop variety V<sub>1</sub>, and moisture content MC<sub>1</sub> gave 82.43%, 77.06%, 87.72%, and 82.84% cleaning efficiency, respectively.

**Keywords:** Sugarcane, leaf stripping, trash removal, mitigate

### INTRODUCTION

In Pakistan, sugarcane is an important cash crop which is grown on 1132 thousand ha and has the highest production of 65475 thousand tons (Nadeem *et al.*, 2018). Manual harvesting of sugarcane is laborious and time consuming job which takes 45 to 48% of total cultivation cost (Bastin and Shridar, 2014, Ali *et al.*, 2018). Sugarcane harvesting includes stalk cutting and stripping of dry leaves and tops. Leaf stripping is not only performed at time of harvesting but also during different growth stages of sugarcane to enhance sugarcane yield (Jain *et al.*, 2010). It takes 65% time of manual sugarcane harvesting (Li *et al.*, 2002). About 10% deductions in selling price are observed if trash (leaves and tops) is not removed properly (Ashfaq *et al.*, 2014). Therefore it is required to remove the dry leaves before transporting to mill. Burning is most common practice to remove trash from standing crop stalks before harvesting (Dawson and Boopathy, 2007). Initially this practice was considered easy and cost beneficiary but studies have revealed that burning practice not only decreases the sugar content but also reduces weight, sweetness and organic material from soil (Cansee, 2010). Furthermore this burning action produces ash contents in air of size less than 10 $\mu$  which causes asthma, bronchitis and other lung diseases (Dawson and Boopathy, 2006). Mechanical leaf stripping provides appropriate alternative to burning by using compressed air and centrifugal leaf cleaners in large scale and small scale sugarcane harvesters,

respectively (Li *et al.*, 2002). These harvesters include whole stalk harvester and chopper harvester. About 79% of farmers in Pakistan have land holdings <5ha. Farmers in country are not capable to buy these harvesters due to social and economic aspects (Anonymous, 2016). Climate conditions, crop height, crop variety and harvest system affects the trash amount (Romero, 2009). According to Chandel *et al.* (2011) trash contents vary from 6-8 t/ha which gives an estimate that annually 188 thousand tons of trash is produced in Pakistan. This trash can be used for trash farming, as a source of renewable energy, for production of biofuel, ethanol and other bio products. Trash farming fixes 50-200 kg of Nitrogen per hectare per year, reduces 50% of tillage expenditures, increase water retention period, increase 28% revenue and decrease 10% cultivation cost (Mendoza *et al.*, 2001). Trash contents of sugarcane contains one third of energy content which is not recovered and 90% of trash is burnt in the field. In India, sugarcane trash is reported to meet 50% of energy crisis (Ashfaq *et al.*, 2014). In Pakistan, no serious attentions are made towards sugarcane leaf stripping machinery and farmers are depending upon local labour. Keeping in view the need of leaf stripping machine and benefits of trash, a small scale sugarcane stripping machine was designed, fabricated with locally available material and was evaluated for its performance in sugarcane field. The machine was designed for capacity of 3.5 ton/hr. and operated by 3 skilled persons.

## MATERIALS AND METHODS

**Main components of sugarcane leaf stripping machine frame:** The frame was designed according to required strength and space. It compiled individual components to work together. The major task of the frame was not only to support the working parts but it also reduced vibrations produced during machine operation. Extensive vibrations may cause damage of machine or affect performance of different machine components.

**Feeding chute:** Feeding chute was provided to facilitate the sugarcane feeding. The feeding chute was joined with machine at 10° horizontal angle for safe feeding as recommended by (Kumar *et al.*, 2002).

**Intake rollers:** Two rollers (upper and lower) were used to make a combination of intake rollers. Intake rollers were provided just after the feeding chute. Three types of intake roller combinations were fabricated.

1. Roller with mild steel (MS) bars (C<sub>1</sub>)
2. Roller with springs supported by continuous rubber bars (C<sub>2</sub>)
3. Roller with springs supported by discontinuous rubber bars (C<sub>3</sub>)

The lower roller was fabricated with mild steel (MS) bars and upper roller was changed for above stated three options.

**Intake rollers with mild steel bars:** First combination of intake rollers was fabricated with mild steel (MS) bars on which rubber was mounted to avoid scratches on sugarcane stalk. The design of roller has been described below. Equation 1 was used to calculate minimum thickness of bar which might resist deflection in bar during pass of sugarcane (Anonymous, 2017).

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

Where,  $\sigma$  is bending strength of mild steel ( $1.6 \times 10^8$  N/m<sup>2</sup>),  $L$  is length of M.S bar on roller (21.32 cm),  $b$  is width of bar (1.95 cm),  $F_{cr}$  is crushing strength of sugarcane taken as 750 N given by (Bastin and Shridar, 2014). The calculated thickness ( $d$ ) of bar was 0.62 cm.

The designed parameters of roller included linear velocity ( $v$ ) 334 cm/s and roller radius ( $r$ ) of 12cm. Angular velocity ( $\omega$ ) of roller was calculated by equation 2 given by (Li *et al.*, 2013)

$$\omega = \frac{v}{r} \quad (2)$$

The designed angular velocity was 27.83 rad/s. Required revolutions ( $N$ ) to gain this angular velocity were calculated by equation 3 given by Gbabo *et al.* (213) and there were 266 revolutions per minute.

$$N = \frac{\omega \times 60}{2\pi} \quad (3)$$

Circumference of roller ( $C$ ) was 75 cm, calculated using equation 4.

$$C = 2\pi r \quad (4)$$

The crushing strength of the sugarcane stalk was 750 N and tensile strength of the leaf sheath was taken 92 N which was double than suggested force to remove the sheath by (Sandhar *et al.*, 2001). This indicated that when a force greater than 92 N will be applied, the stalk sheath will be broken and if applied force increases beyond 750N, it will damage sugarcane stalk. So it was considered that spring should deflect after 92 N and before 750 N. Half of crushing strength (350 N) was chosen for safe spring design (Magalhaes *et al.*, 2004). The design of the spring was made according to procedure and equations given by (Budynas and Nisbett, 2006) and material selected was music wire.

Let the selected spring wire diameter ( $d_w$ ) was 0.4 cm and design considerations included, constant of rigidity ( $G$ ) for music wire (80 GPa), specific weight ( $\gamma$ ) for music wire (8.7 g/cm<sup>3</sup>), maximum deflection ( $\delta=3.81$  cm), factor of safety ( $n_f$ ) 1.25, weight of roller and shaft (130 N), pre-load on each spring  $F_{min}$  (32.5 N), design force for spring  $F_{max}$  (350 N) and spring constant  $k$  (91.8 N/cm). The ultimate tensile strength ( $S_{ut}$ ) was calculated by equation 5.

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

Where, the values of constants  $A$  and  $m$  were 2211 MPa and 0.145 respectively. The ultimate shear strength ( $S_{su}$ ), shear yield strength ( $S_{sy}$ ) and endurance limit ( $S_{se}$ ) was 1211, 813.77 and 267.13 MPa, respectively. The spring index ( $C_s$ ), number of active coils ( $N_a$ ) and solid length ( $L_s$ ) of spring was calculated by equations 6-9 (Budynas and Nisbett, 2006).

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

The value of spring index was 5.57. Here  $\alpha$  and  $\beta$  are constants. The mean diameter of the coil was 2.28 cm, calculated by equation 7.

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

There were 23 active coil turns calculated by equation 8.

$$N_a = \frac{G d^4}{8 k D^3} \quad (8)$$

Solid length of spring was 9.2 cm, calculated by equation 9.

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

The free length of spring was 13.58 cm, calculated by equation 10, given by Khurmi and Gupta (2005).

$$L_f = L_s + \text{deflection} + (0.15 \times \text{deflection}) \quad (10)$$

The weight of spring was 180 g, calculated by equation 11 (Budynas and Nisbett, 2006).

$$W = \frac{\pi^2 d^2 D N_a \gamma}{4} \quad (11)$$

Required diameter of shaft to rotate the roller was calculated by equations 13 (Ashraf *et al.*, 2007).

$$d = 3 \sqrt{\frac{16 \tau}{\pi S_s}} \quad (12)$$

Material selected for shaft was cast iron the calculated diameter of shaft for safe operation was 0.9 cm. The required horse power to rotate the shaft was calculated by equation 12 (Khurmi and Gupta, 2005) and calculated value was 0.12 hp.

$$hp = \frac{n \times \tau}{5252} \quad (13)$$

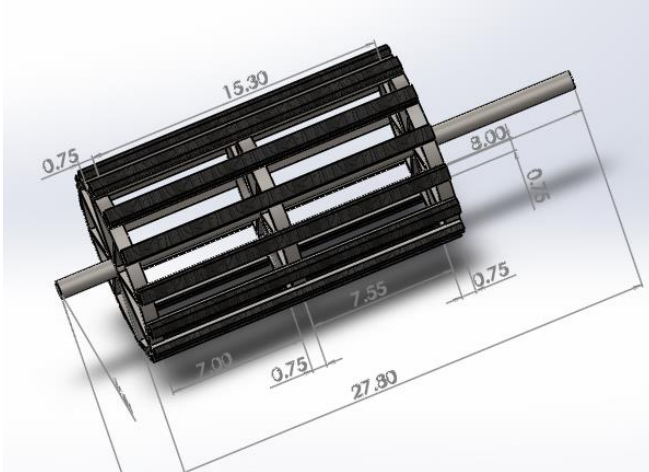


Figure 1. Intake roller with straight mild steel bars.

**Intake roller with springs and rubber bars:** The lower roller of intake rollers set was kept same as above. Only upper roller was changed and second type of roller was designed in which springs were provided along roller periphery to prevent stalk damage and press the individual stalk efficiently when stalks of different diameter were fed into the machine. The design considerations of spring were same as previous one and spring specifications included the following.

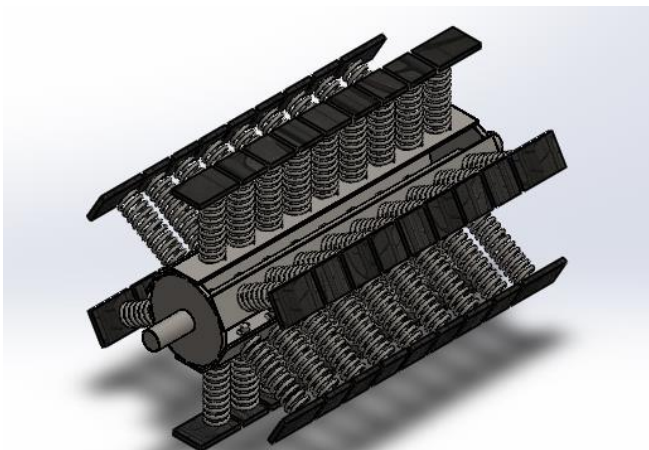


Figure 2. Intake roller with springs and rubber bars.

The spring index (C), mean diameter of spring, inner diameter of spring, outer diameter of spring, number of active coils, solid length, free length and weight of spring was 6.2, 24.8

mm, 20.8 mm, 28.8 mm, 11 turns, 44 mm, 87.8 mm and 84.9 g respectively calculated by using equations 6-11. Mass of rotating drum was 15 kg and radius of the roller was 0.12m. The required power to rotate the shaft was calculated as 171 W and calculated diameter of shaft to rotate the drum was 1.1 cm. The design of roller with discontinuous rubber bars was same as above. The only difference was that in this roller each spring was acting separately.

**Cleaning element:** was portion, where leaf and sheath removal of the sugarcane stalk took place. The material for cleaning element was of prime importance in this regard. Researches have elaborated that macromolecular material is best suited rather than metallic material. Because metallic material can scratch the sugarcane stalk and remove eyes from nodes (Meng *et al.*, 2009). Depending upon the locally available material, the material selected for cleaning element was tire ply. It was cut into pieces of 40 cm length. The necessary calculations for cleaning element are described below.

Let the width of cleaning material made a contact with sugarcane stalk (b) was 3.8 cm and the interaction depth of cleaning material with sugarcane stalk (d) was 1 cm. As it formed a rectangular bar so moment of inertia was calculated by equation 14 (Anonymous, 2017) having value of  $3.17 \times 10^{-9} \text{ m}^4$ .

$$I = \frac{bd^3}{12} \quad (14)$$

Penetration resistance of sugarcane stalk was 29.74 kN (Bastin and Sharidar, 2014), E was modulus of elasticity for thread ply rating 10 taken as  $2.06 \times 10^8 \text{ Pa}$  given by (Clark, 1981) and allowable deflection in ply bar ( $\delta$ ) was 2 cm. The length of 2.7 cm was calculated by equation 15 given by (Anonymous, 2017) for trash removal without stalk damage.

$$L^3 = \frac{3 \delta E I}{P} \quad (15)$$

Literature cited suggested that there must be some spiral angle which not only increased the striking force but also rotates the sugarcane inside the machine. So cleaning material bars had spiral angle of  $18.5^\circ$ .

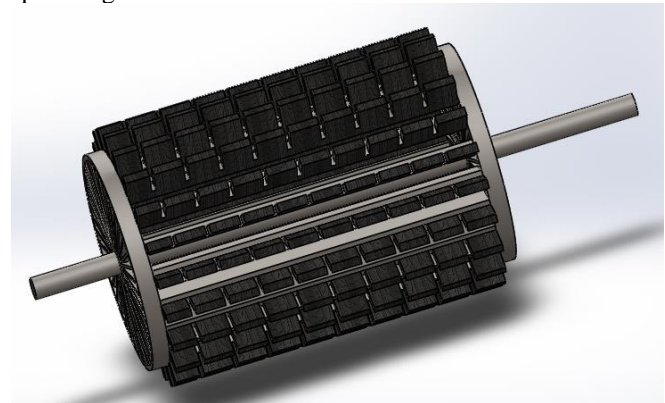


Figure 3. Cleaning element.

**Power transmission system:** Power transmission system transmitted power to different parts of machine. The transmission system of machine had different parts including clutch, shafts, chain and sprockets, belts and pulleys.

**Outlet roller:** Two outlet rollers were provided at end side of the machine. The function of outlet rollers was to provide a support to stalk during cleaning action and push it out of the machine after cleaning. The design procedure and specifications of outlet rollers were same as the intake roller with straight mild steel bar.



Figure 4. Sugarcane stripping machine.

**Experimental procedure for performance evaluation:** The factors were elected to evaluate the machine performance for leaf stripping efficiency were intake roller combinations, cleaning element speed, moisture contents of leaves and sugarcane variety.

Intake roller combinations were tested to check effect of combine and individual pressing of sugarcane stalk on leaf stripping efficiency. Three velocities (CE<sub>1</sub> (660 rpm), CE<sub>2</sub> (763 rpm) and CE<sub>3</sub> (1033 rpm) of cleaning element, two level of sugarcane leaf moisture content, M.C<sub>1</sub> (8.20) and M.C<sub>2</sub> (17.60) and three sugarcane varieties, V<sub>1</sub> (US-658), V<sub>2</sub> (HSF-240) and V<sub>3</sub> (CPF-249) were selected for machine performance evaluation. All the data was statistically analyzed at 5% level of confidence and three replications. The leaf stripping efficiency was calculated by equation 17 (Bastin and Shridar, 2014).

$$\eta_d = \frac{M_1 - M_2}{M_1 - M_3} \quad (17)$$

Where, M<sub>1</sub> was Mass of de-topped cane, M<sub>2</sub> was Mass of de-trashed cane and M<sub>3</sub> was Mass of clean cane.

## RESULTS AND DISCUSSION

**Effect of intake roller combination (C):** The intake rollers not only helped to take sugarcane stalk inside the machine but also helped to press the sugarcane stalk. Figure 2 indicates that the effect of intake roller combination C<sub>3</sub> was significantly different from C<sub>2</sub> and C<sub>3</sub> whereas effect of C<sub>1</sub> and C<sub>2</sub> was not different from each other. The highest mean value of 82.43% for cleaning efficiency was observed with roller combination C<sub>3</sub>. The lowest cleaning efficiency mean of 69.67% was observed with roller combination C<sub>1</sub>. This was due to the fact that when two sugarcane stalks with different diameter were fed in the machine, the healthy stalk was pressed efficiently but thin stalk passed from intake rollers without pressing. The roller combination C<sub>2</sub> faced the same problem as in this combination although springs were used to press the sugarcane stalk but these all springs were connected to each other with the help of rubber bars which prohibited the springs to act separately. When one spring was pressed due to sugarcane stalk, it slightly forced the neighbor spring to deflect creating more space between rollers. This created space caused the same action as was observed in roller combination C<sub>1</sub>.

**Effect of cleaning element speed (CE):** Not only the cleaning material but speed of cleaning element was also important aspect in leaf stripping process. The appropriate cleaning material saved the sugarcane stalk from scratches and its speed helped in removing the stalk sheath. Figure 6 shows the effect of cleaning speed on leaf removal efficiency. The figure indicates that effect of CE<sub>3</sub> was significantly different from CE<sub>1</sub> and CE<sub>2</sub> while effect of CE<sub>1</sub> and CE<sub>2</sub> was not significantly different from each other. Similar results were



found by Ashfaq *et al.* (2014) that with increase in cleaning element velocity the cleaning efficiency of the machine was increased. This was due to increase in number of strikes of cleaning element with sugarcane stalk with increase in velocity. The highest efficiency of 77.06% was gained with CE<sub>3</sub> and lowest value of 73.38% was achieved with CE<sub>1</sub>.

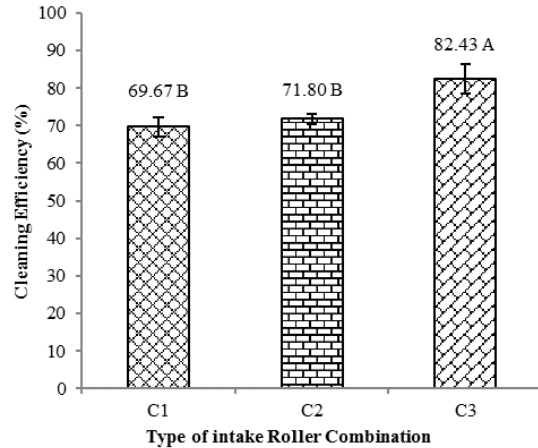


Figure 5. Effect of intake combination on cleaning efficiency.

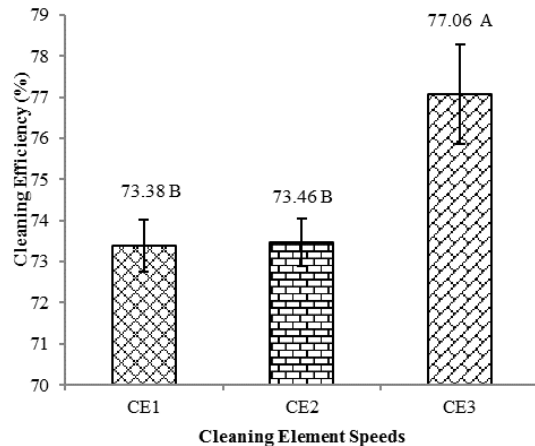


Figure 6. Effect of cleaning element speed on cleaning efficiency.

**Effect of moisture content (M.C):** Moisture content directly influences leaf stripping efficiency. Two levels of moisture contents were selected and their effect on stripping efficiency. Figure 7 shows that the moisture content has significant effect on leaf stripping efficiency. The effect of MC<sub>1</sub> was significantly different from MC<sub>2</sub>. The mean value of 82.84% for leaf stripping efficiency was observed for MC<sub>1</sub> and mean value of 66.43% was observed for MC<sub>2</sub>. The reason behind this behavior was that first level of moisture was at full maturity stage of crop when the leaves and sheath on sugarcane stalk was dried. This dry matter was pressed and loose more efficiently by intake rollers and was stripped off

easily by cleaning element. Whereas second level of moisture was reason of strong grip of green sheath around sugarcane stalk making it difficult for stripping machine to remove it. Similar behavior was observed by Mou *et al.* (2013).

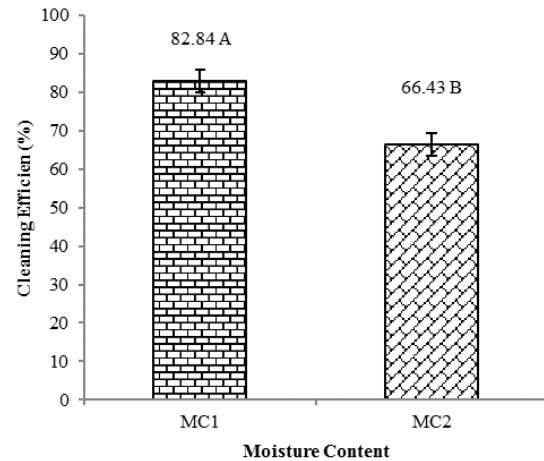


Figure 7. Effect of moisture content on stripping efficiency.

**Effect of crop variety (V):** To check feasibility of different sugarcane varieties, commonly sown three varieties were selected. Figure 5 shows that effect of V<sub>1</sub> was significantly different from V<sub>2</sub> and V<sub>3</sub> while effect of V<sub>2</sub> and V<sub>3</sub> was not significantly different from each other. This fact was because of loose wrapping and small amount of sheath around the sugarcane stalk for variety V<sub>1</sub>. For sugarcane varieties V<sub>2</sub> and V<sub>3</sub> the sheath was tightly wrapped around the stalk. The highest mean efficiency of 87.72% was observed for V<sub>1</sub> and mean efficiency of 68.09% was observed for both V<sub>2</sub> and V<sub>3</sub>. The effect of crop variety for sugarcane leaf stripping was also observed and stated by Ashfaq *et al.* (2014).

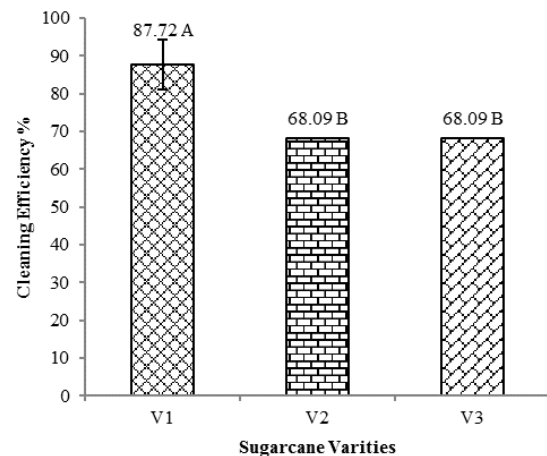


Figure 8. Effect of crop variety on leaf stripping efficiency.

**Conclusion:** Keeping view the current status of labour and machinery shortage for agricultural operations at peak

harvesting time and importance of sugarcane trash, a small scale sugarcane leaf stripping machine was designed, fabricated and tested for its leaf stripping efficiency. The data calculated during testing procedure was analyzed at 5% confidence interval and followings results were concluded. Intake roller combinations type C<sub>3</sub> gave 82.43% leaf cleaning efficiency. The results indicated that pressing of sugarcane stalk soften the sheath. C<sub>2</sub> also gave good results but when variation in sugarcane stalk diameters was more, C<sub>2</sub> combination did not work effectively. Increase in cleaning element speed increased the leaf cleaning efficiency. Cleaning element speed CE<sub>3</sub> gave 77.06% leaf cleaning efficiency. Increase in cleaning efficiency also damaged eyes on nodes. Sugarcane crop leaf moisture had direct effect on leaf cleaning efficiency. Moisture content MC<sub>1</sub> (8.2%) gave 82.84% cleaning efficiency indicating that reduction in leaf moisture enhanced leaf stripping efficiency. Different sugarcane varieties have different amount of extraneous material. Sugarcane crop variety V<sub>1</sub> (US-658) gave 87.72% cleaning efficiency. More efficiency of this variety over other two varieties was due to soft and small amount of extraneous material.

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