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De-trashing of sugarcane: A review

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Abstract
Sugarcane is a sturdy, low risk cash/industrial crop grown in tropical and subtropical areas. Its growing importance is growing steadily as revealed from the fact that world's sugarcane area was increased four times during 1950-2011. The cultivation of sugarcane is energy intensive (143.9 GJ ha^{-1}) as well as labour intensive (3300 man-h ha^{-1}). The farmers quite often suffer from labour shortages particularly during harvesting, mainly due to engagement of local labour in various government sponsored schemes. De-trashing including de-topping is labour intensive operation. It accounts for 65% of the labour involved in harvesting Therefore mechanized de-trashing of sugarcane seems to be the best option to address this problem. A description of mechanized de-trashing of sugarcane that has been reported in the literature is presented and detail of a suggested mechanized de-thrasher is also reported in this paper.

Keywords: Sugarcane, de-trashing, de-topping, harvesting

Introduction

Agriculture and allied sectors forms the major industry generating employment to millions of people. India is the largest consumer and second largest producer of sugar after Brazil. Cash crops such as sugarcane have significant share in GDP of the nation. Sugarcane (*Saccharium officinarum* L.) is the main source of sugar in India and holds a prominent position among cash crops. The specie *Saccharum officinarum* is widely cultivated in India due to high sucrose content (GOI-2013). Sugarcane and sugar industry together impact the life of the livelihood of over 50 million farmers and their dependence involved in cultivating sugarcane in an area of about 5.0 M ha (19.07% share in world). Average annual production of sugarcane is around 355 MT (18.17% share in world), which is used to produce around 30 MT of sugar. The domestic consumption of sugar is reported to be 26 MT (*Niti Ayog*, 2020) [46]. The sugarcane productivity of India (78.25 t ha^{-1}) is higher than global average of 70.77 t ha^{-1} (Statista, 2020) [54].

The cultivation of sugarcane is energy intensive (143.9 GJ ha^{-1} reported by Kumar *et al*., 2018) as well as labour intensive (3300 man-h ha^{-1} reported by Yadav *et al*., 2001) [64]. In general, due to implementation of various government schemes such as MGNREGA, rural employment was generated at gross root level. Consequently, the availability of labour is restricted and in turn, the farmers suffer with serious challenges of labour shortages particularly during peak working season. Harvesting is one of the major operations responsible for increase in production cost of sugarcane. About 45-48% of the total cost of cultivation is incurred in manual harvesting. Manual cleaning of the leaves is carried out mainly through de-topping (removal of tops from mature joint) and de-trashing (removal of leaves from harvested cane stalk) that are labour intensive operations. It accounts for 65% of the labour involved in harvesting (EI-Yamani and Basiouny, 2016). The availability and cost of labour required in harvesting is a challenging task to farmer within his limited economic resources. Therefore mechanization of harvesting operations seems to be the appropriate strategy to resolve this problem.

Table 1: Why sugarcane: a miracle crop

Why sugarcane: A miracle crop? Sugarcane is one of the world's as well as India's best established industrial crop that is efficiently grown and harvested to produce food and bio-energy (Cane growers, 2012). This crop involves less risk and farmers are assured up to some extent about return, even in adverse condition. Sugarcane also provides raw material for the second largest agro-based industry after textile (Magdum *et al.,* 2016). Sugarcane is a hardy crop (Siddaling and Ravikiran, 2015) [58] i.e. cultivated in tropical and sub- tropical regions for its sucrose content and by-products such as molasses and bagasse (the waste fibrous residue).	1. Why sugarcane: a miracle crop? 2. Physical properties of sugarcane 3. Mechanical properties of sugarcane 4. Sugarcane de-trashing methods 5. De-topping of sugarcane 6. Mechanized sugarcane de-thrasher 7. Performance evaluation and factors 8. Energy for cutting force 9. Ergonomics in de-trashing 10. Labour and cost analysis 11. Cane quality, environmental & health hazards

Physical properties of sugarcane crop

Height and stem diameter: Sugarcane is a tall tropical grass with a single un-branched stem of average height in the range of 3 to 4 m with a stem diameter ranges from 3 to 5 cm depending on the species (Blackburn,1984) [9].

Node, internode and root band: The node consists of a growth ring or intercalary meristem, the root band (containing root primordial) and a bud above the leaf scar where the leaf sheath attaches, which delimits the node from the inter node. The transverse cross section through an inter node reveals vascular bundles surrounded by parenchyma cells with a thick outer epidermis covered in an external layer of wax (Moore and Nuss, 1987) [44]. The inter node length can reach over 30 cm, depending on growth conditions, and stems normally reach 2-3 m in the normal growing season (Bull, 2000) [11].

Internode volume: The internode volume reduces towards the top of stalk. In mid-season (August) crop internode-size increases along the stalk with the largest internode occurring at the bottom of the plant. Growth of variety (CP80-1743) is more concentrated in the lower internodes. (Sinclair *et al.*, 2005) [59].

Plant growth: The plant growth is distributed all along the stalk and is not focused on one particular zone. Plant lodging has the negative impact, uniformly distributed over the entire stalk. Differences in varieties were reported on decrease in the growth of the stalk. (Sinclair *et al.,* 2005) [59].

Optimum spacing for planting: The optimum spacing for planting of sugarcane is 0.9-1.0 m between rows. In subtropical India, where growth of the plant is restricted due to climatic parameters, a row spacing of 0.75m is adopted. Even though there are different planting systems for sugarcane, the ridges and furrows system of planting is very common in South India. Important parameters for designing are the optimum spacing of the crop divider and the effective width of the base cutter (Hunsigi, 1993) [22].

Leaves: The leaves are usually attached alternately to the nodes, thus forming two ranks on opposite sides. The mature sugarcane plant has an average total upper leaf surface of about 0.5 m^2 and the number of green leaves per stalk is around 10 (Miller and Gilbert, 2009) [41]. The physical and mechanical properties of sugarcane leaves are also necessary for the design consideration of the relating storage, handling and processing equipment. The mean diameter of the thrash top, width and thickness increases with the increase in moisture (w.b.) from 23.4% to 73.9% (Khongton and Sudajan, 2014) [29].

Ripening and maturation phase: The ripening and maturation phase in a 12-months crop lasts for about 3 months (270-360 days). Sugar synthesis and rapid accumulation of sugar takes place during this phase and vegetative growth is reduced. Cane ripening proceeds from bottom to the top and hence bottom portion contains more sugars than the top portions. (Netafilm, 2010) [45].

Weather: Ample sunshine, clear skies, cool nights and warm days (*i.e.*, more diurnal variation in temperature) and dry weather are highly conducive for ripening (Netafilm, 2010) [45].

Trash content: The trash content at the time of harvesting is reported to be 38.6% where the regular de-trashing processes are skipped by the farmers (Bastian and Shridar, 2014) [4].

Physical parameters influencing design: The physical parameters of sugarcane influencing the design of a whole stalk sugarcane harvester consist of the length and diameter of mill able cane. These were measured for sugarcane variety Co-86032 and were found to vary between 1200-2700 mm and 40 – 20 mm respectively. The trash content at the time of harvesting was 38.6% where the regular de-trashing processes were skipped by the farmers (Bastian and Shridar, 2014) [4].

Mechanical properties of sugarcane

Mechanical properties of the sugarcane stalks are to be considered in the development of a sugarcane de-thrasher. The design of the major unit operations such as de-topping, with de-trashing depends upon the above properties. Mechanical properties of plant stems are important in the design of a de-thrasher as the force and energy requirements are by and large dependent on these properties (Bastian and Shridar, 2014) [4]. It was further reported that the hardness, shearing, tension, compression and de-trashing forces play an important role in the design of de-thrasher (Bhaholyotin *et al*., 1988).

Impact energy: The results impact tests verifies that the impact energy varies with the location of the nodes, increases from top to root (2.0 to 4.0 kg- m). The inner tissue of the stem is softer and more elastic in the upper parts of the cane. (Miyabe *et al.,* 1979) [1].

Quasi-static test: Chattopadhyay and Pandey (1991) conducted the quasi-static test using a universal testing machine to determine shear, compressive résistance and bending resistance of forage crops.

Hardness, force required tensile and bending strength: Mechanical properties of sugarcane were studied and related it with the design performance of sugarcane cleaner. The hardness and bending strength increases but the split tensile strength decreases from top to base of the cane. The force required to de-tach and de-top the trash from the cane stalk varies for different varieties (Sandhar *et al*., 1999) [56].

Normal pressure, friction force and traction force: Miyabe and Abe (1976) [1] conducted tests with the forces necessary to remove the leaves of cane sugar, using universal testing machine and observed that the traction force to remove the leaves varies with position on the stem and the direction of application., Paulo *et al*., (2004) [47] studied the mechanical properties of the sugarcane by compression tests using the universal testing machine. Leaves removal test using friction was also conducted by a special apparatus designed to allow the registration of the normal and traction force. He found that the sugarcane stalk can resist up to 4.9 MPa. It was further observed that with a normal pressure of 0.8 MPa, corresponding to a friction force of 315N, it was possible to remove the leaves, independent of its location in the sugarcane stalk.

Flexural modulus and flexural strength: Qingting *et al*. (2006) reported that the flexural modulus and flexural strength of basal stalks of sugarcane were 1172 MPa and 46 MPa respectively.

Young's modulus, cutting resistance, penetration resistance and crushing force: Bastian and Shridar (2011) carried out study on mechanical properties of the plant for the design of sugarcane harvesting system and found that these were also significantly influenced the performance of the different unit operations in combine harvester. The mechanical properties of sugarcane stalk *viz*., bending resistance; cutting resistance, penetration resistance and crushing resistance were studied in the laboratory. It was found that the Young's modulus of the sugarcane stalks was 86 MPa, the specific cutting resistance varied between 1764.56 - 957.48 kNm^{-2}, penetration resistance ranged between 29.74 - 56.33 kNm^{-2} and the crushing force varied from 0.75 - 1.53 kN.

Compressive and shearing strength, shearing energy and cutting stress: Kanchan *et al*., (2015) studied mechanical properties of sugarcane stalk including compressive and shearing strength of sugarcane stalk for 4 varieties (Co-9904, Co-671, Co-85004, and Co-86032). The highest value of compressive strength (47.75 kN) at lower section was recorded for the variety Co- 86032. On the other hand, the lowest value (34 kN) was obtained with variety Co-85004. The maximum value of compressive strength for top section (49.25 kN) was recorded with CoC-671 and minimum (39.75 kN) for the variety Co-99004. The cutting force required for shearing sugarcane stalk, ultimate cutting stress and specific shearing energy were determined at two sections for all the 4 varieties. It was observed that the maximum value of shearing force (1333.89 N) was recorded for the variety Co-85004 at lower section and it was recorded minimum (815.29 N) for the variety CoC-671. The maximum value of ultimate cutting stress was (1.98 MPa) with variety Co-85004 at the lower section, while it was minimum (1.05 MPa) for the variety Co-99004. Similarly, the maximum value of specific shearing energy (39.68 $MJmm^{-2}$) was recorded for the variety Co-85004 for the lower section, while it was minimum (13.06 $MJmm^{-2}$) with variety CoC-671.

De-trashing Methods

De-trashing is the removal of tops and leaves (trash matter) from the stalk by techniques other than burning (Bastian and Shridar, 2014) [4]. The traditional methods of sugarcane harvesting in developing countries was to burn the dry leaves in standing crop and then cut the stalk manually Dawson and Boopathy (2007) [16].

The un-burnt, un-topped cane contained 22.2% tops and leaves, whereas burnt, topped cane of the same variety contained only 3.2% (Beer *et al*., 1989) [15]. Sugarcane stalk at the time of harvesting is composed of 8% cane tops, 15% green leaves 70% stalks for milling, 7% dry leaves and the tops and leaves has to be removed before milling (Rozeff, 1994) [51]. Dry cleaning is the word commonly used to indicate the leaf and impurities removal process other than burning and washing. Removal of green leaves and tops manually can easily fatigue labour due to excessive stress on muscles and joints (Clemenson and Hansen, 2008) [14].

Manual method

The conventional method of de-trashing is considered as manual de-trashing, the trash is removed with the help of sickle and by pick sugarcane stalks one by one. The manual de-trashing is labor intensive and time consuming job (Ashfaq *et al*., 2014) [3].

Indian Institute of Sugarcane Research (IISR), Lucknow and Tamil Nadu Agriculture University developed hand tools for de-trashing of sugarcane (Kishore *et al*., 2017) [26].

Mechanical method

Mechanized de-trashing can be achieved mainly by two methods *viz*. cleaning the leaves with compressed air or centrifugal cleaning method. A variety of mechanisms have been investigated by different researchers for the removal of tops and leaves. Loose leaves can be removed pneumatically using high velocity air. The efficiency of Pneumatic separation method depends on the quantity and velocity of the air used (Bastian and Shridar, 2014) [4].

De-trashing mechanism: Another method of de-trashing sugarcane consists of a series of rubber belts with grooves cut perpendicular to the longitudinal axis along the outer surface. The grooves open as the belt moves over the pulley and close as the belt travels between pulleys. As a result of this action loose leaves are picked up and separated from the cane. An overall trash removal rate of 30-40% was achieved using a set of 8 such belts on chopped cane pieces 400 mm in length. The main problem with such a system was achieving adequate contact between the belt surface and cane at normal industrial conveying rates (Cochran and Clayton 1968) [12].

Caillouet (2001) reported that a cleaning mechanism consists of a powered rotatable cleaning shaft supporting elongated flexible members, in direction such that the plurality of flexible members contact a cane stalks and force leaves on a cane stalk in the direction towards the base of a cane stalk to remove the leaves from the cane stalk.

Fig 1: Hand tools for de-trashing of sugarcane developed by TNAU

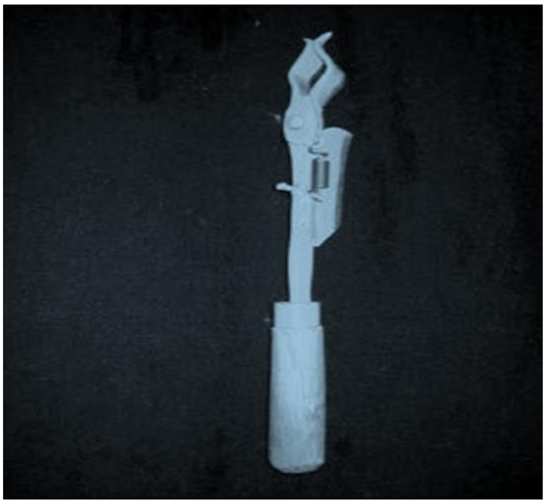

Fig 2: Hand tools for de-trashing of sugarcane developed by IISR

Centrifugal cleaning: Extensive experimentation was conducted on ways of stripping leaves from cane at harvesting. Rotating cylinders with different types of stripping fingers were tried. The fingers were made from spring steel, steel, chain, wire rope, rubber, Teflon and fiber reinforced rubber. Rigid elements tended to break easily, while others like wire ropes and rubber suffered excessive wear. The most successful appeared to be piece of rubber hose mounted on two pairs of cylinders (Ramp 1965).

Robert (1972) [50] used hexagonal rolls to clean whole cane and found that average trash removal of 50% and a cane loss of 1%. Special arrangements had to make to feeder chain to ensure that the mat of cane was no more than 3 stalk thick so that adequate contact of the cane with the cleaning rolls was obtained. Three staggered sets of rolls were required to achieve such degree of cleaning. The power consumption for cleaning roll systems is higher than for pneumatic systems.

Abe *et al*., (1979) [42] found that in impact-friction system flexible cords were attached to rotating rollers that provided a large impact force (centrifugal) on sugarcane stalk that promoted removal of leaves.

Clayton and whittemore (1970) reported that research on cleaning trash from the chopped sugarcane began in 1964 with a research contract at the Louisiana State University, Agricultural Engineering Department. Different polygon shaped rolls were developed and tested in that research. The most efficient polygon rolls was found to be of127 mm (5”) diameter hexagonal rolls. It was further observed that 153 mm (6”) diameter spiral rolls was equally efficient for chopped cane. Both of those rolls were operated alongside of the harvester and reduced the trash content from 20% to 8% on an average. Rubber husking rolls were observed to be more efficient than the steel rolls in removing the immature tops.

Pneumatic separation: Loose leaves can be removed pneumatically using high velocity air. Miyabe *et al*., (2000) [42] examined the separating performance of the trash by the air in order to develop a sugarcane de-thrasher. The results showed that with increasing the wind velocity of blower (9.53 m s^{-1} to 12.3 m s^{-1}), the trash rate of cutting raw material cane (length of 20 cm and 30 cm) was decreased by 2.6% - 2.3%, 3.2% - 2.8% respectively (initial trash rate 17.6).

Cleaning element: Meng *et al*., (2003) [39] studied on cleaning mechanism of leaves of sugarcane and reported that the cleaning elements in the brush shape are the key part of small-scale sugarcane harvesters used in hill areas. The optimum design of cleaning element was based on the method of numerical simulation orthogonal experiment. The brush type cleaning element strips away the leaf from the stalk under the centrifugal way. The high-speed rotating cleaning elements separates the leaves from the sugarcane by pushing, rubbing and striking.

De-topping mechanism of sugarcane

Ruback and Haines (1977) developed a topping mechanism capable of selective delivery of cane to tops to either side, for use in two-ways sugarcane harvester. The mechanism consisted of a pair of contra-rotating, in running cutters that were always rotated in same direction and assisted the discharge of cut tops for both direction of top delivery. The cutter was mounted on them, hub member carrying a projecting feed member served both together the cane tops and discharged them. A top deflector was pivotally mounted between the cutters and according to its position deflected the tops selectively towards either of the cutter according to the desired direction of delivery.

Landry and Andre (1985) described an attachment for a sugarcane harvester for gathering, severing and chopping or shredding the non-mill able, immature top portions for a sugarcane stalk. The attachment includes a scroll-type gathering system interconnected with a rotary knife assembly to form one integral unit with the knife assembly. Upward and rearward inclined gathering system were provided for engaging and lifting the leaves on the upper portion of the sugarcane stalk and guided the same rearward in relation to sugarcane harvester.

Backwith (1995) [10] invented whole stalk sugar cane harvester that tops, cuts, cleans and loads. The canes are flexed forward by the movement of the harvester by means of a roller, while the base is cut with a pair of counter rotating disk cutters per row. The base cutters automatically follow the level of the ground using by spherically dished sliders pivotally connected to cutter shafts. The topped canes, with attached green and dry leaves are fed gently but firmly into the front section of the machine through a single, full width, large 100 dm^2 throat, helped by vertical and-horizontal rubber rollers. By the action of the rotation of preferably three pairs of rollers and paddles, rocks, tramp iron, cans, bottles, soil, and mud, fall through the paddles, and through grizzlies back to the ground; all materials over 0.05 Mt. are retained by the grizzlies, which can be emptied at the operator’s choice. Inside the body of the harvester, bellow and above the cane, a series of special rubber rollers that continuously increase in peripheral speed, spreads and advances the cane. As the cane proceeds further and faster into the harvester's body, all leaves are detached, and eventually fall through the rollers and brushes to a conveyor that is moving up, on the bottom of the harvester's body; this conveyor empties through an opening of the body. The clean cane at an adjustable speed from 7 - 9 ms^{-1} is discharged from the rear of the body at an elevation to fill a semitrailer hitched behind of the prime mover.

Mechanized sugarcane de-thrasher

In developed countries, sugarcane harvesting is done by whole stalk harvester or by chopper harvester. Chopper harvester has facility to chop the whole stalk of sugarcane into the billets. But these billets are required to be transported to sugar mills within 3 days otherwise quality will be deteriorated (Ma *et al*., 2014) [35].

Ramp (1967) [49] developed sugarcane de-thrasher at Louisiana and found that the stripping cylinder method was the most efficient and economical for the maximum removal of cane leaves when the cylinders were equipped with rubber strippers, the de-trashing harvester method was superior to the conventional cutting and burning method.

Srivastava and Singh (1990) [62] developed a tractor PTO driven sugarcane de-thrasher for removal of green as well as dry trash from the harvested sugarcane. It consisted of a cane feeding beater, a cane take off beater, a pair of rollers, a lower and a feeding trough. It was reported that the efficiency of de-trashing was dependent upon the peripheral speed of de-trashing rollers.

Shukla *et al.*, (1991) [57] developed snapping roll type sugarcane cleaner. It separated the top from the cane by breaking it from mature cane and removed the green and dry leaves. The cleaner consisted of feeding chute, cylinder, lower roller, side roller, flap roller, blower and inclined platform fitted on a rigid frame. The machine was tested on different varieties. The machine output with single cane feeding varied between 3.80- 8.23 q h^{-1}.

Indian Institute of Sugarcane Research (IISR) developed tractor-operated sugarcane de-thrasher. It was powered through a tractor PTO drive. The de-thrasher consisted of mechanism of cane feeding, de-trashing and delivery. It could be transported on three point linkage of the tractor and operated by an electric motor, diesel engine or tractor PTO (Singh and Solomon, 2015) [61].

Lin *et al*. (2012) [31] introduced the large-scale sugarcane stripper with automatic feeding. It consisted of automatic feeding module, cleaning leaves module, collecting module and control module. The machine was an important part of the segmental type sugarcane harvester, as it solved the highest labour intensity problem of cleaning leaves. It was found very useful in collection of sugarcane and cleaning their leaves particularly in hilly areas, wherein labour productivity was greatly enhanced.

Bastian and Shridar (2014) [5] developed sugarcane de-trashing test rig and evaluated in terms of de-trashing efficiency and the cane velocity in de-thrasher unit. The variables selected for investigation were input roller speed, de-thrasher roller speed and spiral angle for de-trashing brushes. Out of 4 different orientations of the brush type cleaning system, can bottom feed with brush rotating in same direction and cane top feed with brush rotating in opposite direction system showed higher de-trashing efficiency.

Performance evaluation, damage, adaptability and factors affecting de-trashing

Performance evaluation In the course of testing developed hand tools for de-trashing of sugarcane the stripping capacity and damaged caused to stalk was found to be 119.75 kg h^{-1} and 6.1% respectively at IISR, Lucknow, while the respective figures were 123.25 kg h^{-1} and 3.5% at TNAU, Coimbatore (Kishore *et al*., 2017) [26].

An overall trash removal rate of 30-40% was achieved using a set of 8 such belts on chopped cane pieces 400 mm in length. The main problem with such a system was achieving adequate contact between the belt surface and cane at normal industrial conveying rates (Cochran and Clayton 1968) [12].

Ashfaq (2014) [3] studied the performance evaluation of sugarcane stripper. The experiment was conducted on 3 varieties of sugarcane V1 (COL1148), V2 (FH-237), V3 (MO-240), 3 sprocket speeds NS1 (250 rpm), NS2 (200 rpm), NS3 (150 rpm) and 3 blower speeds NB1 (750 rpm), NB2 (1000 rpm) NB3 (1500 rpm). He found maximum sugarcane stripping efficiency of 79% with sprocket speed of NS3 (150rpm) and blower speed of NB3 (1500rpm) for all varieties of sugarcane.

Ashfaq *et al., (*2014) [3] evaluated performance of sugarcane stripper at AMRI, Faisalabad. Three different varieties of sugarcane were chosen in this study and it was found that variety has non-significant effect on trash removal rate at 5% probability level. Also it was reported that trash removal rate increases by increasing the blower speed air thrust on sugarcane stalk.

Mawla (2014) [37] investigated the mechanical harvesting of sugarcane and it was found that in McConnell harvester system total extraneous matter levels for green whole-stalk cane, cut, cleaned and loaded by the new system, is usually less than 10% and many samples were below 5%. Cane variety and yield are the main variables.

Ikram *et al*., (2019) [24] designed fabricated and evaluated performance of Indigenous sugarcane leaf stripping machine. He found that sugarcane trash (leaves + tops) removal takes 65% time of manual harvesting. The machine was evaluated in its performance for 3 inlet roller combination types (C_1, C_2, C_3), 3 relative velocities between intake rollers (VR_1=1.3, VR_2=1.7, VR_3=1.9), 3 velocities of cleaning element (CE_1=660, CE_2=763, CE_3=1033 rpm), 3 sugarcane verities (V_1=US-658, V_2=HSF-240 and V_3=CPF-249) and 2 levels of moisture contents (MC_1=8.2% and MC_2=17.6). The data calculated during testing procedure was analyzed at 5% confidence interval. The results revealed that, intake roller combinations type C_3 gave 82.43% leaf cleaning efficiency. The results further testified that pressing of sugarcane stalk soften the sheath. C_2 also gave good results but when variation in sugarcane stalk diameters was more, C_2 combination did not work effectively. Increase in cleaning element speed increased the leaf cleaning efficiency. Cleaning element speed CE_3 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_1 (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_1 (US-658) gave 87.72% cleaning efficiency. Higher efficiency of this variety over other two varieties was due to soft and small amount of extraneous material.

The performance of IISR developed tractor-operated sugarcane de-thrasher was evaluated by feeding different varieties of harvested canes, with their tops first, to the de-trashing rollers through the feeding chute. The trash left on the cane after passing through the de-thrasher varied in the range of 1.5% to 6.6%. Trash removal efficiency varied between 77.5% and 95% depending on the variety. The output of the de-thrasher varied with the number of canes passed at a time. The output of de-thrasher was 2.4 t h -1 (Singh and Solomon, 2015) [61].

Adaptability of sugarcane de-thrasher: Lili (2008) conducted an experiment to improve the adaptability of sugarcane de-thrasher to lodged sugarcane, and advance its combined de-trashing performance, using straight and bending sugarcane as subject investigated, The rupture rate of straight sugarcane was fewer than the bending sugarcane's brook-in by cleaning elements or seized off because of playing all around. So the impurity of straight sugarcane was larger than the bending sugarcane's, while the rupture rate of straight sugarcane was smaller than the bending sugarcane. Under the comprehensive combination of parameters: cross depth of elements was 8 mm, rotational speed of de-trashing roller was 601 rpm, distance of run-in roller was 288 mm, rotational speed of deliver roller was 250 rpm, the result of indoor proof test of de-trashing gained, the impurity rate and rupture rate of straight sugarcane was 0.64% and 0% respectively, the impurity rate and rupture rate of bending sugarcane was 0.41% and 16.67%. The adaptability of sugarcane de-thrasher to lodged sugarcane may improve effectively, and its combined de-trashing quality advances after improvement. Therefore, the result of optimization may be used as reference for designing of sugarcane de-thrasher.

Moontree *et al.*, (2012) [43] presented research on developing sugarcane harvester using small engine in order to focus on its appropriateness in sugarcane farming for farmers who are encountering problems of labor shortage and sugar factories lacking sugar cane for producing sugar. It was operated by 180 hp (134.28 kW) at 2500 rpm. Sugarcane was harvested at 12 months after planting with an average-stalk length of 1.8 m, and average-stalk diameter of 25.4 mm (1"); each clump consisted of 8 to 12 stalks, the distance of each sugarcane row was 1.20 m. The percentage of sugarcane-cut stalks was 100% since this engine was installed with double blades with a speed of 1,090 rpm; a speed of leaf-cutting blades was at 669 rpm with the break-even point of 1,22,572.8 kg year-1 and the payback period of 2 years.

Pneumatic separation: It was found that an air velocity of 25 ms^{-1} blown through 150 mm long cane pieces was sufficient to remove 98% of the loose-leaf trash. It was further found that pneumatic separation was ineffective on green mature stalk because its density was close to that of matured stalk. Thus, tops which have had most of their leaves removed as a result of billeting cannot be separated by pneumatic means. The amount of leaf trash varies significantly for different cane varieties, or different cultivation conditions (Corchran and Clayton (1968) [12]. It was also reported that, leaf stripping depends upon the maximum dynamic pulling force (Kojima *et al.*, 1986) [27].

Cleaning element: Li *et al.*, (2002) [34] stated that the materials of the brush shape cleaning element are steel rope and a rubber element. The installation of the cleaning element also affects the cleaning efficiency. Ergonomics known as Man-Machine-Environment System, deals with the machine, its operator and working environment as a complete system affecting the intended work performance. Bastian and Shridar (2014) [5] found that out of the 4 different orientations of the brush type cleaning system, cane bottom feed with brush rotating in same direction and cane top feed with bush rotating in opposite direction system showed higher efficiency. The de-trashing efficiency was increasing with de-trashing roller speed and optimum arrived was 13.75 ms^{-1} with a spiral angle of zero degree. The cane velocity in de-thrasher unit is directly proportional to input roller speed and the de-thrasher roller speed inversely proportional to spiral angle. The cane velocity decreased as the spiral angle increased from 0^0 to 30^0 irrespective of input roller speed and de-thrasher roller speed. The maximum cane velocity was found at 0^0 in all the combinations of de-thrasher roller speed and the input roller speed.

Singh and Sharma (2009) [60] developed a power operated de-thrasher. The trash removal efficiency of the machine varied between 77.5%and 94.5% depending upon the variety. The output of the de-thrasher was 2.4 t h -1with a feeding rate of 2-3 cane stalks at a time. There was a saving of about 17% in the cost of operation and 84% in labour requirement using the de-thrasher as compared to manual method.

Factors affecting de-trashing efficiency: The main factors affecting de-trashing efficiency are speed of de-trashing plate, speed of input and output roller, distance between input roller and de-trashing plate and the distance between output roller and de-trashing plate (Wang *et al.*, 2006) [63]. Certain parameters, such as physical and mechanical properties of sugarcane, the speed of cleaner, geometrical structural dimensions and installation of the cleaning element are some of the factors; significantly affect the de-trashing efficiency and quality (Bastian and Shridar, 2014) [5]. The important factors that affects the reacting force and stress of cleaning element are primary parameters of the leaf cleaning element, intersectional depth, spiral angle, which consist of the arrangement of cleaning element, rotating speed of cylinder and material of the cleaning element (Meng *et al.*, 2003) [3].

Bastian and Shridar (2014) [6] carried out study in the laboratory on mechanical properties of the sugarcane stalk (bending resistance, cutting resistance, penetration resistance and crushing resistance) for the design of whole cane combine harvester. These properties significantly influence the performance of the different unit operations like de-topping, de-trashing, base cutting in combine harvester.

Cutting of sugarcane stalk

The slicing cut of sugarcane stalk takes place when the knife blade friction causes the fibers or parts of fibers adhering to the knife –edge. As the movement continues, the fibers become separated from the rest of the stem in knife's region, but are still attached. As they become further separated the fibers are stressed in pure tension and hence fail. This process takes more energy, but can be achieved using smaller forces since only few fibers are involved at any one time. Using a serrated edge will have the same effect, but will be more energy efficient (Chancellor, 1958).

A study was carried out on the cutting force required. It used a rotary shaft encoder to measure the speed of the blades and a piezo-electric force transducer to measure the force. The smaller peaks were presumed to be the friction between the fibers and the blade. The test variety of cane was Q124 with an average diameter of 27.8 mm. A typical cutting for a pure impact cut, force in Newton with peak of 430 N (Kroes and Harries, 1996).

A study was also carried out on manual cane knives. It was observed that the impact depends on the plant mass, knife velocity, height of cut above ground, stem diameter, bending resistance and cutting forced applied. The controllable variables while cutting sugarcane was found to be knife velocity, height of cut above the ground and cutting force applied. To minimize cane damage, the blade impact speed must not be reduced below 14 ms^{-1} for low fiber cane varieties and 17 ms^{-1} for high fiber cane varieties (Kores and Harries, 1997).

Song *et al.*, (2006) conducted lab – based cutting test and experimental research on the effect of major machine parameters on the performance of the base cutter of a sugarcane harvester. It was found that the cutting force was proportional to the cutting velocity (when the blade cutting velocity < 618 rpm). On the other hand, they were in inverse relationship (when the blade cutting velocity > 618 rpm).

A simple apparatus was developed to calculate the energy requirement for cutting and topping of sugarcane. The apparatus consisted of crank, sprocket, chain, freewheel, flange, front hub, spindle, frame and the base support. The evaluation test with regard to energy requirement for cutting the top and base of the sugarcane revealed that 15.71 joules and 23.83 joules were needed for these operations (Suleiman *et al.*, 2012).

The study on the economic design of sugarcane harvesting machine was attempted (Zode, 2015). It revealed that the cutting force of sugarcane ranged between 29.14 - 106.57 N.

Ergonomics of de-trashing & harvesting of sugarcane

The sugarcane de-trashing (150 to 210 days after planting) is a highly labour intensive operation. Three types of sugarcane de-thrasher (IISR, OUAT and TNAU) were ergonomically evaluated to assess their suitability (reduction in drudgery and addition of comfort) to farm workers. The TNAU sugarcane de-thrasher (SCD_3), was identified as the lowest value of ergonomic evaluation parameters, highest stripping capacity with minimum damage to sugarcane stalk. Necessary ergonomic refinements (*viz.*, reduction of length of knife supporting stem, sliding supporting stem and knife base, wooden handle for firm grip and reduction of weight) were made to enhance comfort of the operator without jeopardizing the efficiency of the de-thrasher. The mean value of heart rate, energy cost, and oxygen consumption rate in terms of percent VO_2 maximum and work pulse of male subjects with the refined TNAU sugarcane de-thrasher (ESCD) was 101.12 beats min^{-1}, 14.74 kJ min^{-1}, 34.88% of VO_2 maximum and 30.55 beats min^{-1} respectively. The corresponding values for female subjects were 112.76 beats min^{-1}, 16.52 kJ min^{-1}, 47.91% of VO_2 maximum and 44.35 beats min^{-1}respectively. The effectiveness of ergonomic refinements was reflected in terms of significant reduction in physiological stress and increase in stripping capacity (4.9%). The ergonomic refined TNAU sugarcane de-thrasher resulted in cost saving (5.5-6.6%) and time saving (5.6-5.8%) as compared to TNAU de-thrasher. Use of the ergonomic refined TNAU de-thrasher resulted in cost savings (13.0%) and time saving (14.5%) as compared to conventional de-trashing (Kathirvel *et al.*, 2010) [25].

Shukla and Nayak (2018) also reported the ergonomic evaluation of improved technique of traditional and improved sugarcane stripper. The study was conducted with 25 number of farm women in Surajgoan village of District Narsinghpur. Selected 25 farm women were in the age group of 25-40 years with normal health without any major illness. The results are in Table 2.

Table 2: Comparative parameters of traditional sickle and sugarcane stripper

S. No	Parameters	Traditional Sickle	Sugarcane Stripper
1	HR during work beats min^{-1}	120	114
2	WHR average	108	120
3	WHR Maxima	130	118
4	Output, kgh^{-1}	36	45
5	EER Avg. (kJ min^{-1})	10.36	9.40
6	Saving in CCW	-	40%

Labour and cost analysis in sugarcane harvesting and de-trashing

The manual harvesting: The manual harvesting of sugarcane by using tools is highly labour consuming process and costly too. About 850-1000 man –h ha^{-1} is required for harvesting of sugarcane manually (Yadav and Choudhuri, 2000). Labour requirement for cutting and de-trashing of sugarcane was worked out as 157 and 395 man - h ha^{-1}, respectively (Shukla *et al.*, 1991) [57].

Labour requirement: It was reported that overall requirement of labour for sugarcane cultivation is 3306 man-h. Labour requirement for preparatory tillage, planting, irrigation, intercultural and other operations, harvesting and *stripping* are 331, 238, 337, 392, 816, *1192* man –h respectively (Yadav *et al.*, 2001) [64].

Cost of Manual de-trashing: The manual harvesting of sugarcane required 37-40 man-days ha $^{-1}$. It takes 7. 5 man-days ha^{-1} to cut and involves harvesting of 150-175 t ha^{-1} with labours being paid 500-550 Rs $tonne^{-1}$ of harvest. Hence total cost of harvesting was arrived at 75,000 - 87,500 Rs h $^{-1}$. (Siddaling and Ravikiran, 2015) [58]. Manual de-trashing involves 55%-60% share in harvesting cost (Paulo *et al.*, 2010) [48].

Cost of power operated sugarcane de-thrasher: It was found while evaluating the performance of sugarcane de-topper cum de-thrasher that cost of de-trashing by the power operated sugarcane de-thrasher was 1,250 Rs ha^{-1} as compared to the 7,500 Rs ha^{-1} for manual de-trashing. It was concluded that, apart from reducing the cost of cultivation, the drudgery, faced by the labourers, was also reduced considerably (Begam *et al.*, 2014).

The economic evaluation: The economic evaluation of IISR developed mechanical de-thrasher revealed that about 81 man-h ha^{-1} are required for de-trashing of cane with the de-thrasher (de-thrasher output 2.4 t h^{-1} and cane yield of 65 t ha^{-1}) which is less than the labour required by the manual method (520 man-h ha^{-1}). There was a saving of 17% in cost of operation and 84% in labour requirement (Singh and Solomon, 2015) [61].

Cane quality, environmental and health hazards.

Traditional method: The traditional method of reducing the extraneous matter of cane (burning) is unacceptable due to the environmental consequences. Dry cleaning is a means of removal of a significant proportion of this material before the cane is shredded, thus avoiding the negative effects on sugar processing (Ivin and Doyle, 1989). The effect of burning on soil fertility, wind erosion susceptibility and accelerated moisture depletion, as well as the destruction of sucrose in the burnt cane plant and the elimination of energy-rich biomass are relevant factors (Smith *et al*., 1984) [53].

Health hazards: There is a great risk of human hazards in manual operations *viz*. labour's hands are often injured due to the spines and serrated margins of the leaf blade (Paulo *et al.*, 2010) [48]. Sugarcane de-trashing is a highly labour intensive operation. Manual de-trashing leads to serious health hazards for the workers (Karthirvel *et al*., 2010) [25]. In areas where hand harvesting prevails, many of the injuries are machete and other hand tools. These injuries can range from minor cuts to the severing of body parts. Working with cane also very easily produces injuries and cuts to the eyes (Siddaling and Ravikiran 2015) [58].

Environmental problems: In the light of increasing public pressure to minimise environmental pollution, green cane harvesting will probably soon become the norm worldwide (Bernhardt, 1994) [7]. Traditional burning operation to remove the trash contents can cause environmental and health hazard because it produces respirable contents of size less than 10µm (Givens, 1996) [20]. Other disadvantages of sugarcane burning included weight loss decrease in sweetness, high production cost, destruction of organic material and soil structure (Cansee, 2010) [13]. The traditional method of burning cane has been used worldwide for many years. However, the environmental pollution from the smoke and airborne particles is receiving increasing public resistance. Moreover, there is evidence that cane that has been burnt will deteriorate far more rapidly than un-burnt cane (Linnets and Moodley, 1994) [31].

Cane quality: The effects of delivering and crushing green cane, which contains all of the associated extraneous matter, on the cost of production and the quality of sugar are well known. In consequence of these effects the different options for dry cleaning the cane are being considered (Bernhardt, 1994) [7]. Smith *et al*. (1984) [53] argue that green cane harvesting may be a more lucrative practice than burning. Experiments showed that 5- 7% more recoverable sugar was available in matched samples of green versus burnt cane.

Conclusion

Sugarcane is a hardy, low risk cash crop that often suffers problems of labour scarcity at critical growth stages. Its manual harvesting de-topping and de-trashing can easily fatigue labour due to excessive stress on muscles and joints. Since the area under sugarcane in India is very high, the mechanization will play an important role to remove human drudgery and facilitate timely work completion in safe and cost effective manner without jeopardizing cane quality and adequately addressing environmental issues. Mechanized de-trashing employs centrifugal cleaning as well as pneumatic separation that removes up-to 98% of the loose leaf trash. The prominent mechanized de-thrasher developed: IISR-Lucknow - tractor PTO operated (Singh and Solomon, 2015) [61], de-topper cum leaf stripper powered by 6 HP diesel engine (Bastian, 2014) [6], and IIT Kharagpur. Besides some hand tools were also developed by IISR, TNAU and OUAT for de-trashing. Human drudgery is the major constraint while using these hand tools. The traditional manual de-trashing is arduous, labour intensive and time consuming, therefore there is an immense need of designing and developing sugarcane de-topper cum de-thrasher. Moreover, most of the developed tools and prototype models of sugarcane de-thrasher and de-trashing mechanism are still under development stage and needs multi location tests. Conclusive results on the optimum arrangement of components and the de-topping method could not be found and hence a study was undertaken to investigate different alternatives for the development of a cost effective, energy efficient rubber blade type de-trashing system for harvesting sugarcane stalks. The present study to design sugarcane de-topper cum de-thrasher will facilitate to use de-topped leaves of sugarcane stalk for various beneficial purposes. This provision is not available in previously developed sugarcane de-thrasher.

Table 3: A summary of researches conducted on de-trashing mechanism and sugarcane de-thrasher.

Researchers	Research title	Findings
Abe *et al*., (1979) [42]	Development of a leaf-stripping system for sugarcane	Impact - friction system flexible cords were attached to rotating rollers that provided a large impact force (centrifugal) on sugarcane stalk that promoted removal of leaves.
Ramp (1965)	Development of sugarcane de-thrasher	Stripping cylinder method was the most efficient and economical for the maximum removal of cane leaves when the cylinders were equipped with rubber strippers
Meng *et al*., (2003) [39]	Cleaning mechanism of leaves of sugarcane	The brush type cleaning element strips keep away the leaf from the stalk under the centrifugal force. The high-speed rotating cleaning elements separates the leaves from the sugarcane by pushing, rubbing and striking.
Singh and Sharma (2009) [60]	Developed a power operated de-thrasher.	The trash removal efficiency of the machine varied between 77.5% - 94.5%. The output of the de-thrasher was 2.4 th $^{-1}$with a feeding rate of 2-3 cane stalks at a time. There was a saving of about 17% in the cost of operation and 84% in labour requirement using the de-thrasher as compared to manual method.
Bastian and Shridar (2014) [6]	Investigation on sugarcane de-trashing mechanism	The de-trashing efficiency was high at optimum de-trashing roller speed (13.75 m/s).

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