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An overview of key base cutting parameters in Sugarcane harvesters: A review

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ABSTRACT

India was the second-largest producer of sugarcane globally, following Brazil, with a 19.9% share in the total cultivation area (5.16 Million hectares) during the 2018-19 seasons. The country produced around 400.16 million metric tonnes of sugarcane and 31.5 million metric tonnes of sugar. Harvesting sugarcane traditionally required significant manual labor, involving approximately 850 to 1000 man-hours per hectare using conventional tools. Due to labor shortages across the country, there was a growing need to shift from manual harvesting methods to mechanized ones. To support this transition, a study was conducted to identify key base cutting parameters crucial for designing a sugarcane harvester. Several factors influenced the cutting energy, including the stalk's physical and mechanical properties, cutting force, cutting speed, cutting velocity, blade angle, and blade type.

KEYWORDS

Blade Angle, Cutting Speed, Cutting Force, Cutting Velocity, Sugarcane

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Harvesters generally use two cutting mechanisms: the cutter-bar system and the rotating cutting system. For crops like sugarcane with thicker stalks and higher cutting resistance, rotating cutting mechanisms with blades are more common. These rotating cutters generate strong inertia and impact forces, especially when equipped with cutting discs up to 90 cm in diameter (Ma *et al.*, 2014). Sugarcane harvesters are broadly categorized into whole-stalk harvesters and chopper harvesters. Whole-stalk harvesters include a topper and a base cutter. The topper trims the cane tops and moves them aside, while the base cutter slices the cane about 30 mm above the ground level, ensuring efficient harvesting (Esquivel *et al.*, 2008).

A Review of Key Parameters in Base Cutting

Effective mechanization of sugarcane cutting (Base and top) plays a crucial role in optimizing the agro-industrial process. The performance of the base-cutter system significantly influences both the quality of the operation and the reduction of raw material losses, while also contributing to the longevity of the cane field (Max *et al.*, 2012). Several key parameters associated with base cutting are critical in the design and development of efficient sugarcane harvesters. These include the physical and mechanical properties of the cane, cutting force and speed, cutting velocity, blade angle's effect on cutting energy, and the type of blade employed.

Each of these factors directly impacts the effectiveness and precision of the cutting process.

Physical Properties (Sugarcane)

The length and diameter of sugarcane are important factors in designing both the de-topper and base cutting mechanisms. The de-topper blade assembly must be adjusted properly to ensure the top is cut accurately without losing millable cane during harvesting. Since sugarcane diameter varies from top to bottom and differs by variety, measurements are typically taken at the top, middle, and bottom of the cane. For designing cutting systems, the maximum and minimum diameter values are considered to account for these differences. Blackburn (1984) noted that sugarcane is a single, unbranched stalk with an average height of 3 to 4 meters and a diameter between 3 to 5 cm, depending on the species. Miller and Gilbert (2009) highlighted that joint length and diameter vary significantly based on the variety and growth conditions. Nalawade *et al.* (2017) studied the physical characteristics of sugarcane varieties like Co86032, CoM0265 (from Indapur and Dehu in Pune, Maharashtra), and CoS767 (from Kota, Rajasthan). They found that stalk length, weight, diameter, and internode length varied with variety and decreased from the bottom to the top of the cane. Ashraf *et al*. (2016) evaluated the physical traits of sugarcane varieties such as Co-80036, Co-86032, COVSI-9805, Co-8014, and COM-0265. Measurements taken from farmers' fields showed cane lengths between 2000 to 3000 mm, diameters ranging from 30 to 50 mm, and node-to-node distances between 50 to 170 mm. These characteristics varied depending on the variety, soil type, and climate conditions.

Mechanical Properties (Sugarcane)

Research on sugarcane harvesting has focused on understanding the mechanical properties of sugarcane stalks, which are crucial for efficient cutting. According to (McNulty and Mohsenin, 1979) key properties that influence cutting include compression, tension, bending, shearing, density, and friction. These properties can vary based on factors such as species, variety, stalk diameter, maturity, moisture content, and cellular structure (Bright and Kleis, 1964; Persson, 1987).

Taghijarah *et al.* (2011) investigated the shearing characteristics of sugarcane stalks and found that shearing stress ranged from 3.03 to 4.43 MPa. The specific shearing energy was reported to vary between 37.42 and 64.25 MJ mm^{-2}. Similarly, Yadav et al. (2004) studied the performance of sugarcane cutter planters such as the IISR Lucknow-designed ITI and Khalsa PE 630. Their results showed that the force required cutting sugarcane setts ranged from 12.2 to 106.57 N, depending on cane diameter. In the cylindrical cutting system, the cutting force varied between 29.14 and 106.57 N, while in the rotary cutting system, it ranged from 12.2 to 81.20 N. Taghinezhad *et al.* (2012) examined the mechanical cutting properties of sugarcane stalks using a universal testing machine, a linear blade, and a size reduction device. They analysed how different cutting orientations (0°, 45°, and 90°) affected cutting energy. Results showed that the average specific cutting energies for cane internodes were 4.368, 6.978, and 10.021 kN m^{-1} for 0°, 45°, and 90° orientations, respectively. For cane nodes, the values were 6.458 kN m^{-1} at 0° and 15.812 kN m^{-1} at 90°. Their research highlighted notable differences in cutting properties based on orientation, nodes, and internodes.

Samaila *et al*. (2012) developed a machine to measure the energy required for cutting and topping sugarcane. Their findings showed that cutting the top required 15.71 joules, while cutting the base required 23.83 joules. Bastian *et al*. (2014) investigated the mechanical properties of sugarcane variety CO-86032, including bending resistance, cutting resistance, penetration resistance, and crushing resistance. They found the Young's modulus of sugarcane stalks to be 86 MPa. The specific cutting resistance ranged from 1764.56 to 957.48 kN m^{-2}, while penetration resistance was between 29.74 and 56.33 kN m^{-2}. The crushing force varied from 0.75 kN to 1.53 kN. For sugarcane stalks with diameters between 40 mm and 50 mm, the maximum cutting force recorded was 2.7 kN at the bottom and 1.04 kN at the top.

Cutting Force and Velocity of the Cutting Blade

Cutting forces and cutting speeds are crucial factors in designing energy-efficient equipment for cutting plant materials.

Research conducted by (Gupta and Oduori, 1992) explored how system parameters such as blade oblique angle, cutting disc tilt angle, and blade cutting velocity influence the cutting force in a knife-type sugarcane base cutter. Their findings indicated that an optimal blade cutting velocity should fall between 13.8 and 18.4 m/s, as power consumption rises significantly when the velocity exceeds 19.4 m/s. They also identified that the recommended blade oblique angle ranges from 20° to 50°, while the suitable operating tilt angle lies between 25° and 50°. Song *et al.* (2006) determined that the machine's forward speed has the most substantial impact on the cutting force requirements of a sugarcane base cutter. Factors such as blade oblique angle, cutting disc tilt angle, and the number of blades installed also contribute to cutting force demands, albeit to a lesser extent. They proposed an experimental equation that estimates the cutting force based on system parameters like forward speed, blade cutting velocity, and disc tilt angle. This equation has the potential to support advancements in base cutter designs.

In a related study (Liu *et al*., 2007) investigated the effects of blade cutting velocity, disc tilt angle, and blade oblique angle on the cutting force. Their results demonstrated that cutting velocity had the most pronounced effect on unit cutting force, showing a generally linear relationship. Higher cutting velocities correlated with greater unit cutting force requirements. Srivastava *et al.* (2007) also examined the influence of cutting disc tilt angle and blade oblique angle, finding that these factors played a role in cutting force requirements, albeit to a lesser degree than cutting velocity. As the knife advances through the material, the plant fibres are deflected before ultimately failing under tension. Mathanker *et al.* (2015) further confirmed that cutting power requirements increase with higher cutting speeds. Their research indicated that the lowest average cutting power occurred at a 60° oblique angle with a cutting speed averaging 7.9 m/s.

Impact of Blade Angle and Design on Cutting Energy

Gupta and Oduori (1992) explored how blade angle and design impact cutting energy. They found that a blade speed of 13.8 m/s, an oblique angle of 35°, and a tilt angle of 27° were ideal for a revolving knife-style sugarcane base cutter.

Clementson and Hansen (2008) observed that the cutting force required for sugarcane stems varied based on the blade design. They reported a 26% difference in cutting force between the two designs they tested. Additionally (Igathinathane *et al*., 2010) found that positioning a cutting blade parallel to a corn stalk (0°) rather than perpendicular (90°) significantly reduced specific cutting energy by one-tenth for internodes and one-fifth for nodes. Ghahraei *et al.* (2011) identified optimal angles for cutting Kenaf stems: a knife edge angle of 25°, and shear, oblique, and rake angles of 40°. Meanwhile, research by (Miao, Grift, Hansen, and Ting, 2011) showed that hammer mills outperformed knife mills in reducing energy cane size.

Mello and Harris (2000, 2003) studied how different types of base cutter blades affect performance. Their findings showed that blades with serrated edges caused less damage to plant stems compared to smooth-edged blades. Moreover, serrated blades with a short-serrated pitch of 3 mm needed less energy for cutting than smooth blades. The design features such as blade shape (whether forward or backward curved) and serrated pitch were identified as key factors for serrated blade performance. Toledo *et al*. (2013) observed that tilting cutting blades from the perpendicular axis of the base cutter reduced damage to sugarcane. They also found that combining serrated blades with standard base cutter discs helped achieve a desired cutting height within the range of 0 to 100 mm. Habib *et al.* (2002) examined the impact of knife edge angle and the moisture content of plant material. Their research revealed that harvesting consumes significantly less energy than crushing, mainly due to the influence of moisture content.

Cutting Blade Types: Plain and Serrated Edges

Researchers like (Frazzetta, 1988, Mello and Harris (2001) explored how blade design affects cutting performance. Mello and Harris (2001) conducted lab tests comparing smooth-edge and serrated blades. Their results showed that serrated blades performed better, requiring less cutting force and energy. This improved efficiency is due to the serrated blade’s combined slicing and direct cutting action, which reduces the overall cutting force needed (Mello and Harris, 2000).

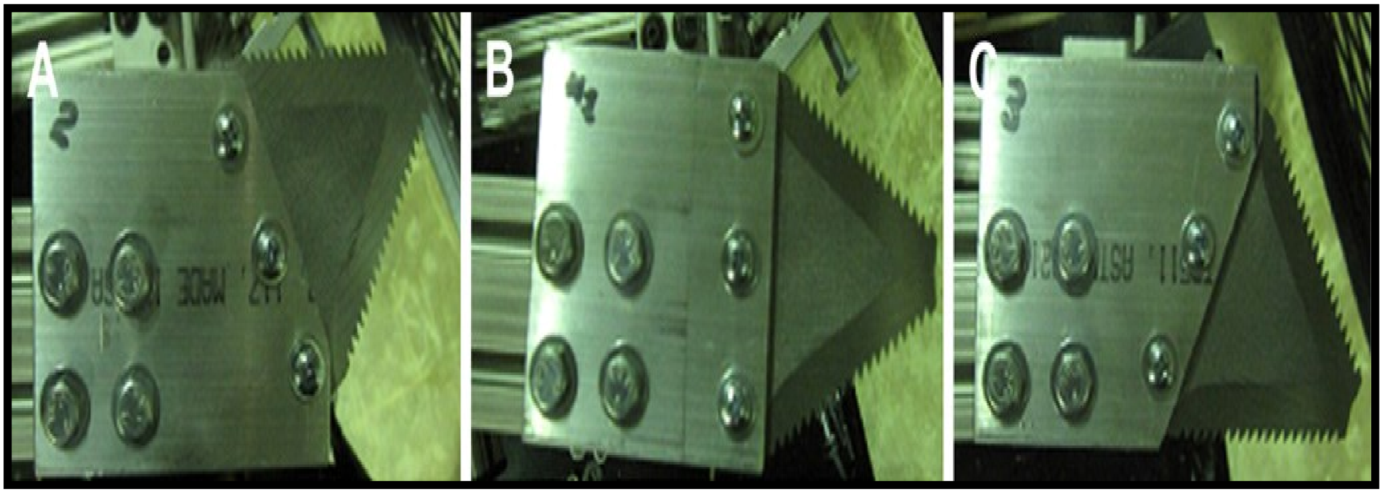

Fig 1. Serrated cutting blade mounted at different oblique angles representing: straight cut (0^0) (A), 30^0 oblique cut (B), and 60^o oblique cut (C). (Johnson *et al.*, 2012)

In 2003, Mello and Harris further investigated serrated blade design by studying two key factors: the length of the serration pitch (the distance between similar points on adjacent projections) and the blade's curve direction (forward or backward). They tested these factors using blades with 3 mm and 7 mm pitches. The results showed that forward-curved blades with a 3 mm pitch provided the best cutting efficiency for cane cutting (Mello and Harris, 2003). The improved performance with smaller pitches may be because they have more projections per unit length, making it easier for the blade to penetrate and cut effectively. Momin *et al.* (2017) investigated how different base cutter blade designs impact the quality of sugarcane cuts. They tested four types of blades: a conventional straight blade, a 30° angled blade, a serrated blade, and a straight blade with laser cladding on its underside. Each blade was mounted at a 45° angle on a base cutter attached to a John

Deere 3520 Sugarcane Harvester

The study classified stem and root system damage into nine categories:

- Undamaged stem, not uprooted
- Undamaged stem, partially uprooted
- Undamaged stem, fully uprooted
- Partially damaged stem, not uprooted
- Partially damaged stem, partially uprooted
- Partially damaged stem, fully uprooted
- Severely damaged stem, not uprooted
- Severely damaged stem, partially uprooted
- Severely damaged stem, fully uprooted

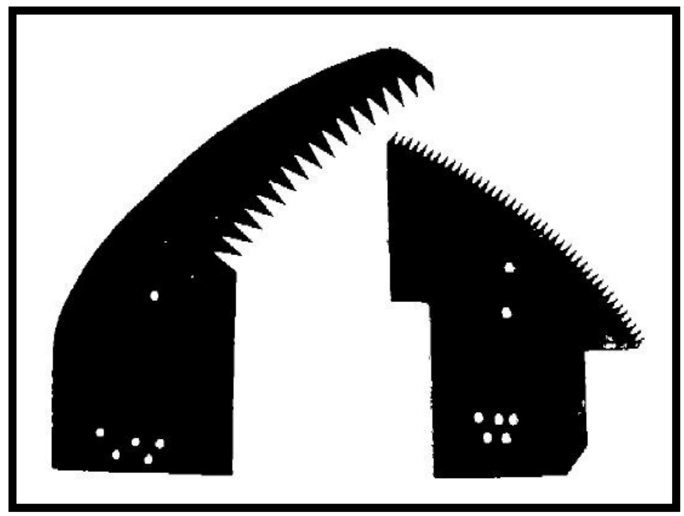

Fig 2. Forward and backward with 15 mm and 7 mm pitches in serration (Mello and Harris, 2001)

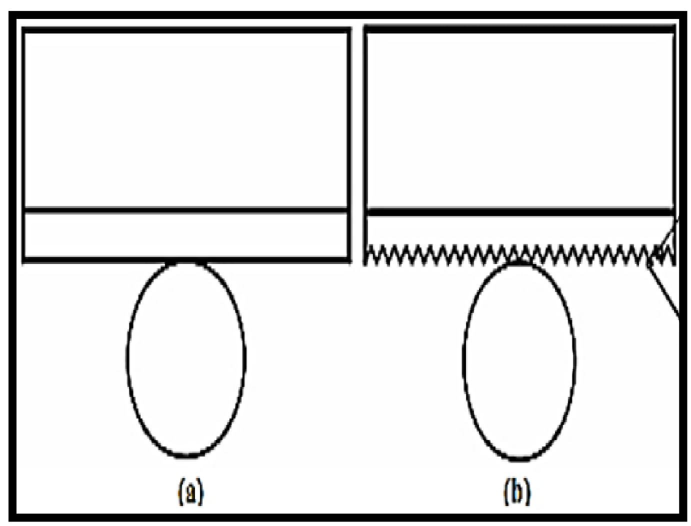

Fig 2. (a) Cutting by the smooth-edged blade; (b) cutting by the serrated blade (Frazzetta, 1988)

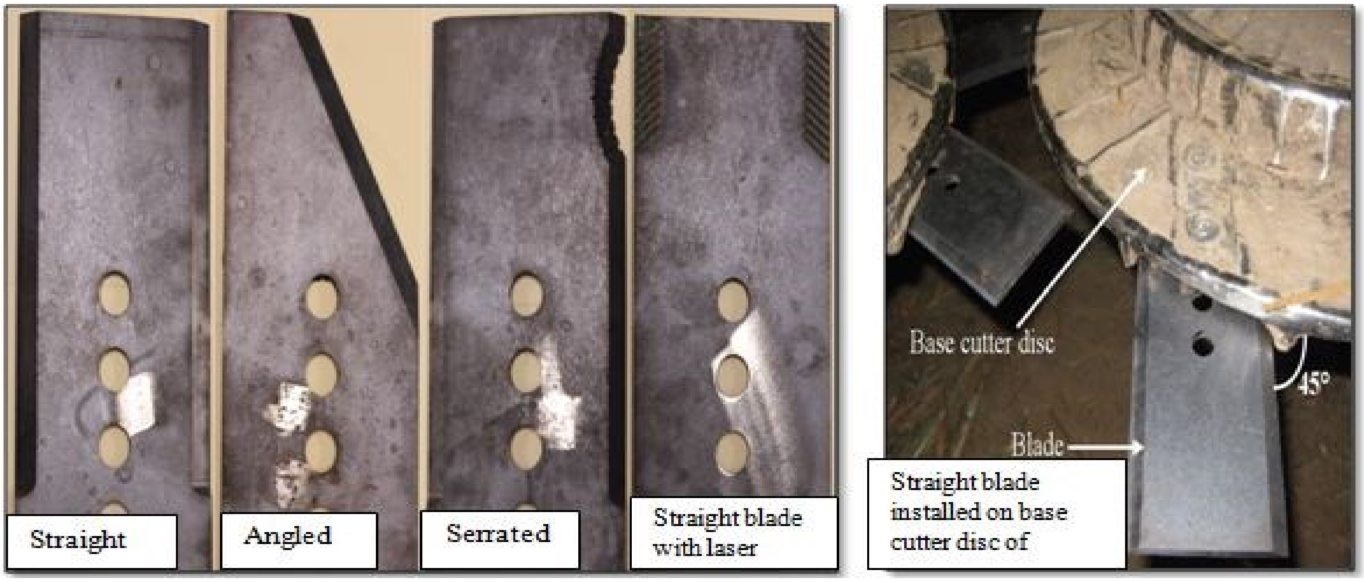

Fig 3. Four blade designs used in the experiments (Momin *et al*., 2017)

The angled blade caused the most damage, with about 38% of stems and 36% of root systems affected. The percentage of undamaged stems for the straight, angled, serrated, and laser-clad blades was 76.9%, 62.1%, 83.1%, and 72.3%, respectively. Partially damaged stems accounted for 11.25%, 21.97%, 11.29%, and 17.73%, while severely damaged stems were 11.9%, 15.9%, 5.65%, and 9.9% for the respective blades. All blades, except the angled one, successfully cut nearly 80% of stems without disturbing the root system, with only 5% of stems being uprooted. This research provided insights into how these blade designs affect sugarcane damage and ratoon crop growth.

Conclusions

This study focused on understanding the key factors required for base cutting parameters for designing and developing a sugarcane harvester. Based on the gathered information, several important cutting parameters were identified, including physical and mechanical properties, cutting force and speed, cutting velocity, blade angles, and blade types. The research examined different sugarcane varieties such as CO 80036, CO 86032, COVSI 9805, CO 8014, and CO 0265. The sugarcane measured between 2000 to 3000 mm in length and had diameters ranging from 30 to 50 mm. The maximum cutting force required at the base of a single cane was 2700 N, while the top required 1040 N.

The crushing force varied from 750 N to 1530 N for canes with diameters between 40 mm and 50 mm. The average shear strength was 3.64 MPa, ranging from 3.03 to 4.43 MPa. Blades with serrated edges were found to cut more effectively than smooth-edged blades. Additionally, serrated blades with shorter pitch lengths consumed less energy. Cutting force increased with cutting velocity when the blade's speed was below 618 rpm. The ideal tilt angle for the blade ranged between 25° and 50°, while the best oblique angle was between 20° and 5°. The most efficient combination of settings was achieved with a blade cutting velocity of 13.8 m/s. An angled blade successfully cut about 80% of sugarcane stalks without disturbing the root system, and only 5% of the stems were uprooted. Using blades with smaller pitches improved energy efficiency, as the increased number of projections per unit length made penetration easier and enhanced the cutting process.

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