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|Research Article|

Design, Development and Performance Evaluation of Five Cylinder Power Operated Sugarcane Crusher

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Abstract- A compact 5-cylinder power-operated sugarcane crusher was designed, fabricated and evaluated for performance across six commercially important sugarcane varieties (CO419, CO62175, CO7804, B37172, CO8371 and CO86032) cultivated in Karnataka, India. The physical and physico-chemical properties of the selected varieties were characterised prior to crushing trials. Machine performance was assessed at three driving pulley speeds (10, 15 and 20 rpm) and benchmarked against four conventional crusher types. At 20 rpm, the 5-cylinder crusher achieved a cane-crushing capacity of 113–120 kg/hr, juice extraction efficiency of 65–70%, and power consumption of only 300 Watts. Across all six varieties, mean juice extraction efficiencies ranged from 68.06% (CO419) to 75.06% (CO62175), representing improvements of 5.30–14.64 percentage points over a comparable 3-cylinder gearbox-type crusher. Juice quality parameters including Brix, sucrose, reducing sugar and purity were also determined. The results demonstrate that the 5-cylinder configuration delivers superior extraction efficiency with reduced energy consumption relative to existing crusher designs, offering a commercially viable solution for small and medium sugarcane processing units.

Keywords: Sugarcane crusher; 5-cylinder crusher; juice extraction; cane varieties; power consumption; physico-chemical properties

1. Introduction

Sugarcane (*Saccharum oflcinarum* L.) is one of the most important agro-industrial crops worldwide, contributing approximately 80% of global sugar production and serving as a key feedstock for ethanol and bio-energy. India ranks second globally in sugarcane production, with Karnataka being among the foremost producing states. The efficiency of juice extraction from sugarcane at the primary processing stage is critical in determining both sugar recovery and the economics of the entire value chain (Rein, 2007).

Conventional power-operated sugarcane crushers used at the small and medium enterprise (SME) level in India predominantly employ 2- or 3-cylinder configurations. While they are widely available, these designs are characterised by limited juice extraction efficiencies, high specific energy consumption, and an inability to effectively crush harder cane varieties in a single pass. The juice yield is significantly influenced by the number of crushing cylinders, roller clearances, peripheral speed, and the physical properties of the cane stalk (Hugot, 1986; Iqbal, 2007; Gbabo *et al.*, 2013). Roller-model extractors typically yield efficiencies in the range of 55–65% depending on cane variety and machine configuration (Gbabo *et al.*, 2013). Small-scale processors in tropical countries therefore frequently encounter sub-optimal juice recovery, resulting in significant economic losses at the farm-gate level (Prasad, 2017).

A novel 5-cylinder crusher configuration was designed to overcome these limitations by subjecting the cane to five successive crushing stages, thereby increasing juice liberation, reducing bagasse moisture content and improving overall extraction efficiency. The present study reports: (i) the physico-chemical characterisation of six commercial sugarcane varieties; (ii) the design, development and fabrication of a 5-cylinder power-operated crusher; (iii) an evaluation of its performance across varying pulley speeds; and (iv) a comparative assessment against conventional crusher types.

2. Materials and Methods

2.1 Sugarcane Varieties

Six commercially cultivated sugarcane varieties CO419, CO62175, CO7804, B37172, CO8371 and CO86032 were selected for the study. Mature cane stalks harvested at recommended crop maturity were procured from the experimental farm of the University of Agricultural Sciences, Bengaluru, Karnataka. Physical characterisation, including stalk length, diameter, weight, fibre content, sucrose content, yield per hectare and surface hardness, was carried out following standard procedures (FAO, 1992; BIS, 2012).

2.2 Design and Fabrication of the 5-Cylinder Sugarcane Crusher

The 5-cylinder sugarcane crusher was designed as a compact, portable unit suitable for use at small-scale jaggery and juice-vending establishments. The crusher assembly consists of one king (feed) roller, two crusher rollers and two extracting rollers arranged in tandem. Roller clearances were set in accordance with the Indian Standard Test Code for Sugarcane Crushers (BIS, 2012): the clearance between the king roller and crusher roller was maintained at 6.4 mm, while the clearance between the king roller and extracting roller was 0.8 mm. Power was transmitted from a single-phase electric motor via a V-belt and pulley drive. The driving pulley speed was varied at 10, 15 and 20 rpm to evaluate its influence on machine performance.

2.3 Performance Evaluation

Performance trials were conducted following the protocol of BIS (2012) at three driving pulley speeds (10, 15 and 20 rpm). For each speed and variety combination, five replicate samples of known initial weight were crushed and the following parameters were recorded: (a) cane crushing capacity (kg/hr); (b) juice extraction efficiency (%); and (c) electrical power consumption (Watts) (Soetan, 2008). Juice extraction efficiency was calculated gravimetrically as the ratio of juice extracted (g) to the initial cane weight (g), expressed as a percentage. For the variety-wise evaluation, stalk samples of each variety were crushed at 20 rpm (optimum speed). Juice quality was determined using a hand refractometer (Brix), the Lane–Eynon method (reducing sugars), a polarimeter (sucrose), and the formula: Purity (%) = Sucrose (%) / Brix (˚) × 100 (Anonymous, 1986). Performance of the 5-cylinder crusher was compared against four conventional crusher types: 2-cylinder, 3-cylinder, 3-cylinder heavy duty, and 3-cylinder gearbox type, using published benchmark data.

3. Results and Discussion

3.1 Physical and Physico-Chemical Properties of Sugarcane Varieties

The physico-chemical characteristics of the six sugarcane varieties are summarised in Table 1. Substantial inter-varietal variation was observed for stalk length, weight, and yield, while fibre content and sucrose content showed comparatively smaller differences.

3.1.1 Maturity Duration and Stalk Length

Varieties CO7804 and B37172 exhibited the shortest maturity duration of 12 months. CO62175 and CO86032 required 12–13 months, CO419 matured over 12–14 months, and CO8371 had the longest duration of 12–15 months. Stalk length ranged from

710–750 mm (CO7804) to 1500–1600 mm (CO86032). The markedly superior stalk length of CO86032 is attributable to its vigorous vegetative growth habit under the prevailing soil and climatic conditions (Bakker, 1999; Verma, 2004).

3.1.2 Stalk Diameter, Weight and Physical Condition

Stalk diameter varied between 32.0 mm (CO62175, CO8371) and 35.5 mm (CO86032). Individual stalk weight ranged from 750–766 g (CO62175) to 1200–1300 g (CO86032), consistent with differences in stalk length and diameter. Varieties CO62175, B37172 and CO86032 were classified as soft in surface condition and are amenable to single-pass crushing, whereas CO8371, CO7804 and CO419 were medium-hard and required multiple passes in conventional 3-cylinder crushers, resulting in higher energy consumption (Gravois, 1992).

3.1.3 Fibre Content, Sucrose Content and Yield

Fibre content varied within the relatively narrow range of 11.5–15.0%, with CO8371 recording the highest fibre (14.0–15.0%). Sucrose content ranged from 13.0–14.0% (CO8371) to 16.0–16.5% (CO7804 and CO86032). Cane yield per hectare was highest for CO62175 and CO86032 (both 180 t/ha) and lowest for CO419 (112.5 t/ha). The inverse relationship between fibre content and juice extraction efficiency reported in the literature (Gravois, 1992) was generally supported by the present findings. Yusof et al. (2000) also reported that sucrose content and total soluble solids (Brix) are among the most reliable maturity indicators, consistent with the high sucrose levels observed in the higher-yielding varieties in this study. The importance of bagasse fibre composition in relation to milling efficiency and cogeneration potential has been further emphasised by Payne (1991).

Table 1. Physico-chemical properties of the six sugarcane varieties under study

Variety	Length (mm)	Diameter (mm)	Weight (g)	Fibre (%)	Sucrose (%)	Yield (t/ha)	Physical Condition
CO419	790–805	32.5	1050–1104	12.0–13.0	15.0–16.0	112.5	Medium Hard
CO62175	750–766	32.0	970–985	11.5–12.0	14.0–14.5	180.0	Soft
CO7804	710–750	34.0	1200–1250	12.5–13.0	16.0–16.5	150.0	Medium Hard
B37172	810–850	33.0	975–1000	12.0–12.5	15.0–16.0	175.0	Soft
CO8371	825–850	32.0	850–900	14.0–15.0	13.0–14.0	150.0	Medium Soft
CO86032	1500–1600	35.5	1200–1300	13.0–13.5	16.0–16.5	180.0	Soft

3.2 Performance of the 5-Cylinder Sugarcane Crusher at Different Pulley Speeds

The developed 5-cylinder crusher is illustrated in Figure 1 and the performance parameters at three driving pulley speeds are presented in Table 2. A clear positive relationship was observed between pulley speed and both crushing capacity and juice extraction efficiency, while power consumption increased inversely with speed reduction.

3.2.1 Cane Crushing Capacity

Cane crushing capacity increased from 90–98 kg/hr at 10 rpm to 113–120 kg/hr at 20 rpm. The higher throughput at elevated speeds reflects greater roller peripheral velocity and reduced inter-crushing dwell time, resulting in more material being processed per unit time.

3.2.2 Juice Extraction Eflciency

Juice extraction efficiency was highest (65–70%) at 20 rpm and lowest (56–58%) at 10 rpm. At intermediate speed (15 rpm) extraction was 62–64%. Higher peripheral speeds appear to generate adequate nip forces to shear and compress the cane effectively, consistent with findings reported by Iqbal (2007).

3.2.3 Power Consumption

Power consumption was 425 W at 10 rpm, 342 W at 15 rpm, and 300 W at 20 rpm. The counter-intuitive reduction in power consumption with increasing speed is explained by the shorter dwell time per unit mass of cane, reducing frictional losses and the

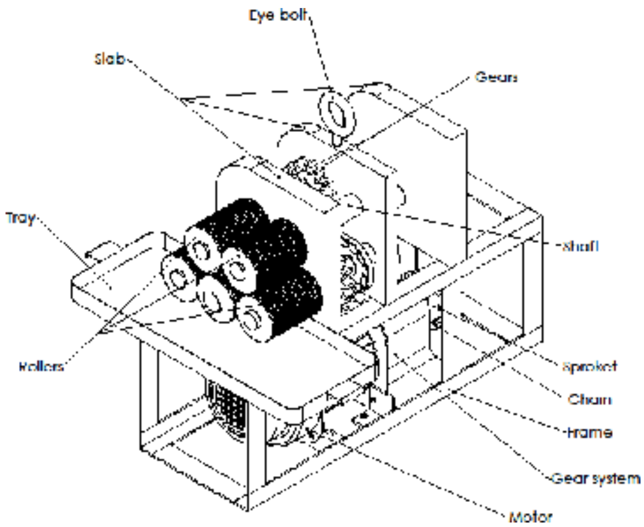

Fig. 1. Compact and portable 5-Cylinder sugarcane crusher.

energy required to overcome the static resistance of the cane-roller interface. A speed of 20 rpm was identified as the optimum, offering the best combination of throughput, extraction efficiency and energy economy.

Table 2. Performance of the 5-cylinder sugarcane crusher at three driving pulley speeds

Sl.	Parameter	20 rpm	15 rpm	10 rpm
1	Cane crushing capacity/hr (kg)	113–120	100–102	90–98
2	Juice extraction (%)	65–70	62–64	56–58
3	Power requirement (HP)	1.0	1.0	1.0
4	Power consumption (Watts)	300	342	425

3.3 Comparative Performance of Crusher Types

Table 3 presents a comparative analysis of the 5-cylinder crusher against four conventional crusher types at 20 rpm. The 5-cylinder design outperformed all conventional types in juice extraction efficiency and achieved competitive crushing capacity with markedly lower power consumption.

3.3.1 Crushing Capacity

The 5-cylinder crusher (113–120 kg/hr) had the highest crushing capacity, closely followed by the 3-cylinder heavy-duty crusher (120–130 kg/hr). The 2-cylinder crusher was the least productive at 25–35 kg/hr. The comparable output of the 5-cylinder and 3-cylinder heavy-duty designs, with the former consuming substantially less power (300 W vs. 525 W), underscores the efficiency advantage of the developed machine.

3.3.2 Juice Extraction Eflciency

The 5-cylinder crusher achieved the highest juice extraction (65–70%), surpassing the 3-cylinder gearbox type (60–65%), 3-cylinder heavy duty (62–64%), 3-cylinder (52–58%) and 2-cylinder (50–55%) crushers. The progressive compression of cane through five roller gaps ensures more complete liberation of cellular juice compared to two or three crushing stages.

3.3.3 Power Consumption

The 5-cylinder crusher consumed 300 W, substantially less than the 3-cylinder (620 W), 3-cylinder heavy duty (525 W) and 3-cylinder gearbox (458 W) types. Only the 2-cylinder crusher consumed less power (240 W), yet delivered markedly inferior extraction efficiency. This favourable power-to-extraction ratio represents a significant advantage for rural and peri-urban small-scale processors operating under electricity cost constraints.

Table 3. Comparative performance of the 5-cylinder crusher against conventional crusher types at 20 rpm

Sl.	Parameter	2-Cylinder	3-Cylinder	3-Cylinder Heavy Duty	3-Cyl. Gearbox	5-Cylinder (Developed)
1	Crushing capacity/hr/hp at 20 rpm (kg)	25–35	72–80	120–130	112–115	113–120
2	Juice extraction (%)	50–55	52–58	62–64	60–65	65–70
3	Power consumption (Watts)	240	620	525	458	300

3.4 Juice Quality from Six Varieties Crushed in the 5-Cylinder Crusher

The juice quality parameters obtained from all six varieties using the 5-cylinder crusher at 20 rpm are summarised in Table 4. Juice purity exceeded 99.7% for all varieties, indicating minimal contamination of the extracted juice. Sucrose content ranged from 20.79% (B37172) to 22.28% (CO8371). Brix values ranged from 19.39° (CO7804) to 21.56° (CO419).

Table 4. Juice quality parameters for six varieties crushed in the 5-cylinder crusher at 20 rpm

Sl.	Parameter	CO419	CO62175	CO7804	B37172	CO8371
1	Juice extracted (g/kg)	692.80	694.50	692.50	684.80	690.80
2	Bagasse weight (g/kg)	307.20	305.50	307.50	315.20	309.20
3	Juice extraction (%)	69.20	69.40	69.20	68.40	69.00
4	Brix (°)	21.56	21.16	19.39	19.45	21.18
5	Sucrose (%)	21.56	21.56	21.74	20.79	22.28
6	Reducing sugar (%)	7.77	7.45	7.28	7.69	7.15
7	Purity (%)	99.74	99.90	99.74	99.73	99.76

3.5 Variety-wise Juice Extraction Efficiency

Detailed juice extraction results for each variety are presented in Tables 5 through 10. In all cases, the 5-cylinder crusher yielded significantly higher juice extraction efficiencies than the 3-cylinder gearbox-type crusher used as a reference. The magnitude of improvement varied with varietal surface hardness and stalk morphology.

3.5.1 CO419

The medium-hard CO419 variety yielded a mean juice extraction efficiency of 68.06% from the 5-cylinder crusher, compared to 61.68% from the 3-cylinder gearbox crusher — an improvement of 6.38 percentage points. The superior extraction is attributed to the additional compression stages forcing juice from the harder fibrovascular tissue (Iqbal, 2007).

3.5.2 CO62175

The soft CO62175 variety exhibited the highest mean juice extraction efficiency of 75.06%, compared to 60.32% with the 3-cylinder gearbox crusher — an improvement of 14.64 percentage points. The combination of soft cane structure and 5-stage crushing proved particularly advantageous for this variety.

Table 5. Juice extraction from CO419 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	710	1116.7	510.3	606.4	223.3	287.0	68.00
2	725	1120.0	522.5	597.5	230.0	292.5	67.00
3	740	1135.5	530.0	605.5	228.5	301.5	67.89
4	720	1115.6	505.5	610.1	220.0	285.5	68.40
5	731	1121.5	505.7	615.8	222.6	279.1	69.03
Mean	**725.2**	**1122.0**	**515.0**	**607.0**	**225.0**	**289.0**	**68.06**

Table 6. Juice extraction from CO62175 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	760	886.5	373.9	512.6	178.4	195.5	72.00
2	745	890.4	360.5	529.9	175.6	184.9	75.91
3	735	887.0	357.5	529.5	184.7	172.8	75.80
4	755	885.8	355.8	530.0	179.5	156.3	75.90
5	760	890.2	361.5	528.7	180.0	160.5	75.70
Mean	**766.0**	**888.0**	**362.0**	**526.0**	**180.0**	**174.0**	**75.06**

3.5.3 CO7804

Despite its medium-hard surface, CO7804 yielded a mean extraction efficiency of 68.66% in the 5-cylinder crusher versus 56.64% in the 3-cylinder gearbox crusher, representing an increase of 12.02 percentage points. The heavier stalk weight of this variety (1200–1250 g) facilitated effective nip engagement across all five rollers.

Table 7. Juice extraction from CO7804 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	680	1301.3	549.5	751.8	227.3	322.2	70.00
2	674	1250.5	540.1	710.4	215.5	324.6	66.14
3	685	1278.5	545.8	732.7	218.6	327.2	68.21
4	700	1290.0	550.0	740.0	223.9	326.1	68.88
5	705	1305.0	551.9	753.1	225.7	326.2	70.09
Mean	**689.0**	**1285.0**	**547.4**	**737.6**	**222.2**	**325.2**	**68.66**

3.5.4 B37172

B37172 (soft variety) gave a mean juice extraction efficiency of 68.84% with the 5-cylinder crusher, compared to 59.88% with the 3-cylinder gearbox crusher (improvement: 8.96 percentage points). The soft surface of this variety allowed efficient single-stage juice liberation in each successive roller gap.

3.5.5 CO86032

The tall soft variety CO86032 recorded a mean juice extraction efficiency of 69.00% with the 5-cylinder crusher versus 63.30% with the 3-cylinder gearbox crusher, an improvement of 5.70 percentage points. Although CO86032 had the longest stalk, the improvement margin was comparatively modest, possibly due to the higher initial fibre content (13.0–13.5%) limiting the incremental gain from additional crushing stages.

3.5.6 CO8371

CO8371, classified as medium-soft, achieved the second-highest mean extraction efficiency of 73.17% with the 5-cylinder crusher, compared to 66.82% with the 3-cylinder gearbox crusher (improvement: 6.35 percentage points). Despite having the highest fibre

Table 8. Juice extraction from B37172 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	700.0	725.6	351.1	374.5	174.9	176.2	68.00
2	690.0	710.0	341.5	368.5	165.5	176.0	66.90
3	710.5	745.5	360.0	385.5	160.0	200.0	69.98
4	705.1	730.0	352.0	378.0	168.5	183.5	68.61
5	715.0	760.0	370.0	390.0	171.0	199.0	70.70
Mean	**704.0**	**734.0**	**355.0**	**379.0**	**168.0**	**186.9**	**68.84**

Table 9. Juice extraction from CO86032 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	600	958.1	422.3	535.8	181.6	240.7	69.00
2	610	962.5	425.2	537.3	186.0	239.2	69.19
3	598	955.2	418.9	536.3	178.0	240.9	69.06
4	590	950.1	415.8	534.3	176.0	239.8	68.80
5	605	960.5	426.8	533.7	185.8	241.0	68.72
Mean	**600.0**	**957.3**	**421.8**	**535.5**	**181.5**	**240.3**	**69.00**

content (14.0–15.0%) among the varieties tested, its moderate surface hardness allowed effective juice liberation in the 5-stage crusher.

Table 10. Juice extraction from CO8371 variety sugarcane (n = 5 replications)

Sl.	Length (mm)	Initial Wt (g)	Bagasse Wt (g)	Juice (g)	Dry Bagasse (g)	Lost Juice (g)	Efficiency (%)
1	750.0	1005.2	411.8	593.4	192.3	219.5	73.00
2	760.5	1010.5	415.6	594.9	193.5	222.1	73.10
3	745.5	1006.0	410.0	596.0	195.0	215.0	73.20
4	752.0	1003.6	408.7	594.9	193.7	215.0	73.06
5	748.0	1015.5	416.9	598.6	196.0	220.9	73.51
Mean	**751.0**	**1008.2**	**412.6**	**595.5**	**194.1**	**218.5**	**73.17**

4. Conclusion

A compact and portable 5-cylinder power-operated sugarcane crusher was designed, fabricated and evaluated for performance across six commercial sugarcane varieties. The following principal conclusions are drawn from this study:

- Among the six varieties assessed, CO86032 exhibited the largest stalk dimensions and highest individual stalk weight, while CO62175 and B37172 offered the highest field yield (180 t/ha). Surface hardness — a critical factor influencing crushing energy and juice recovery — ranged from soft (CO62175, B37172, CO86032) to medium-hard (CO419, CO7804).
- The optimum operating speed for the 5-cylinder crusher was 20 rpm, at which a crushing capacity of 113–120 kg/hr, a juice extraction efficiency of 65–70% and a power consumption of 300 W were achieved.
- The 5-cylinder crusher outperformed all four conventional crusher types evaluated, delivering the highest juice extraction efficiency (65–70%) at the lowest power consumption per unit output among multi-cylinder crushers.
- Variety-wise evaluation demonstrated that the improvement in juice extraction over the 3-cylinder gearbox crusher ranged from 5.70 percentage points (CO86032) to 14.64 percentage points (CO62175), with soft-caned varieties benefiting most from the 5-stage crushing action.
- Juice purity exceeded 99.7% for all varieties, confirming the quality suitability of the extracted juice for further processing.
- The 5-cylinder crusher is recommended for adoption at small and medium-scale jaggery-making and juice-vending establishments as a technically superior and energy-efficient alternative to conventional designs.

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