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Performance Evaluation of Improved and Conventional Sugarcane Crushers: A Comparative Study

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Abstract: Sugarcane is one of the most widely cultivated crops. The conventional and modified sugarcane crushers were compared for their performance evaluation in terms of juice yield, extraction capacity, and efficiency, at the farmer's field. The conventional crusher has three rollers whereas the modified crusher has two rollers for the crushing of the sugarcane. In each juice extraction system, about 0.50 tonnes of cane samples (in ten replications) were crushed to extract the juice. For each sample, juice and bagasse collected were recorded and weighed. The bagasse was exposed to sun and oven drying to reduce moisture. The extraction capacity and juice yield of the modified crusher were also recorded higher than the conventional sugarcane crusher. Statistical results indicated that the modified sugarcane crusher performed better than the conventional crusher as the modified crusher recorded higher juice extraction efficiency (66%). The time taken to process 50 kg sugarcane was higher in conventional sugarcane crushers due to its improper roller alignment and complex structure. It can be concluded that modified sugarcane crushers are more efficient, safe to operate, and easy to maintain. The juice extracted from the modified crusher was also of good quality due to its covered structure and corrosion-free material.

Keywords: Sugarcane Crusher, Juice Extraction Efficiency, Sugarcane Processing, Bagasse, Jaggery Industry.

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1. Introduction

Sugarcane is the world's most widely cultivated crop. Sugarcane is an annual crop belonging to the genus *Saccharum*, family Poaceae, and tribe Andropogon (Ahmad et al., 2021; Ikram et al., 2021). It is cultivated in two seasons in Pakistan, during spring and autumn. It contributes approximately 0.6 percent to the country's GDP and 2.9 % to the agriculture sector. During 2019-20, sugarcane production declined by 0.4 % (67.174 to 66.880 million tonnes). Production may exhibit a trend of the area under cultivation of 1.04 mha compared to 1.1 mha, a decrease of 5.6 percent, with improved yields compared to 2018-19 (Government of Pakistan, 2020).

In recent industrial growth, sugarcane is not only confined to the production of sugar, but its bi-products serve as the basis of several lucrative markets such as gur, molasses, alcohol, sugar beverages, chipboard, paper, confectionery (Dotaniya et al., 2016; Santos et al., 2020; Soloman, 2011) and supply many other industries such as chemical, plastic, synthetic fiber, insecticides and detergents with raw materials (Krishnakumar et al., 2013; Lal et al., 1980). Approximately 50% of the sugarcane produced in Karnataka is crushed in the sugar industries, and 40%

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is crushed to make jaggery, and the remaining 10% is for seed as well as local juice consumption. The remaining part of the bagasse is burned as an energy source (Gangadkar et al., 2016).

Sugarcane contains water (65%), fiber (16%), sugar (15.5%), and non-sugar (3.5%) contents (Gangadkar et al., 2017; Osore et al., 2019; Singh et al., 2021). In sugar mills, 79 % of the juice is pressed by multi-stage crushing, contrarily, in the jaggery industry, about 65% of the juice is pressed in three roller crushers (Priya et al, 2012). Unrefined natural sugar made by continuous heating of sugarcane juice in open pans is called lump sugar or jaggery (Kumar and Kumar, 2021b; Kumar and Kumar, 2021a; Takale, 2021). Very low crushing capacity from obsolete machines is a major cause of the lower juice yield (Priya et al., 2012). For this reason, the crushing of sugarcane to extract maximum juice is critical in the jaggery industry, and the whole cane crushing operation in the jaggery industry demands massive overhauling and needs a better crushing method such that the yield of jaggery increases and the cost of production decreases (Yinggang et al., 2013). In the jaggery industry, sugarcane crushers are required to have efficient juice extraction, fair maintenance, optimum power input, safe operating, resistance to vibrations, wear and tear, and economically feasible for farmers (Ishiwu and Oluka, 2004; Vitrac et al., 2019).

Sugarcane is processed to extract the sugar content using machines including centrifuge, crystallizers, dryer, juice extractor, pan boilers or juice evaporator, etc. (Amosun et al., 2000). In the sugar manufacturing industry, the role of juice extractors is vital as it defines the efficiency of the sugarcane processing plant. Conventionally, A simple juice extractor consists of several rollers, gears, and a lever linked to a cast-iron frame body (Soetan, 2018). Many conventional machines are comprised of a solid and robust cast iron material. These machines were built using a basic rolling and crushing mechanism (Adamolekun et al., 2015; Kulkarni, 2005). A crusher cum scraper for the development of jaggery granules was developed and its efficiency in the recovery of jaggery granules was evaluated. The effect of three system parameters, i.e., running speed, time of operation, and feed rate on the recovery of jaggery granules below the size of 3 mm, was examined. Results showed that the system parameters had a major impact on recovery. Full recovery of (76.52 %) was reported at an operating speed of 20 (rpm), 8(min), and 2 (kg/min). The minimum granule recovery was associated with the higher levels of all three parameters due to the cumulative impact of over-crushing of jaggery chunks and skipping from primary crushing bars. Research has been carried out to create a prototype of the juice extraction machine for sugarcane and integrate it with other features, i.e., cleaning, crushing, and collection method. To collect the juice first, the sugarcane stalks are crushed, then the left fiber (bagasse) is cut into smaller sections and stored in a basket. The crusher assembly will be washed automatically through a cleaning system (Adewole et al., 2015).

In the previous research, the authors studies the designing and working of cane crushers, Olaoye (Olaoye, 2011) designed, developed, and evaluated a sugarcane juice extractor for its functional performance and economic operations. Operating speeds of 0.25, 0.3 and 0.36 (m / s) can result in output capacities of 10.50, 12.00 and 14.25 (kg / h). At operating speeds of 0.25 and 0.36 (m / s), the extraction performance for the system ranged between 40% and 61%. The optimum performance of a machine is sustainable for a longer processing duration mainly due to the bluntness development of the perforated grating drum.

A sugarcane juice extraction machine was designed and developed for the rural community, extract juice from sugarcane and will separate the juice from the sugarcane and the bagasse (Nduka et al., 2019). The machine was tested with a sugarcane sample (22.5 kg), the mass of juice extracted was 4.1 (kg), and the extraction took about 22 minutes. Sugarcane juice extractor of 3340.95-4635.3 (kg/ day) cane crushing capability has been developed and tested. Performance findings of the system using the sugarcane varieties (BD 95-030), (BD 96-009), and the local chewing cane demonstrate a juice extraction efficiency of 72.53-83.9 percent. It was also found to be ideal for extracting juices of various sizes of cane and to be easy to operate and maintain (Gbabo, 2002).

Three-roller crushers have the efficiency to collect 50-55% of the juice (Baboo and Solomon, 2000). Inadequate extraction causes juice loss (∼ 25%) in the bagasse, which is subsequently as fuel in the jaggery industry. Juice extraction can be enhanced to 80% by introducing crushers with more than three rollers/cylinders. A horizontal type roller has a greater juice extraction than a vertical one (Singh, 2004). Hence, conventional crushers need some modifications to improve their juice extraction efficiency to increase the performance of cane crushing.

Table 1. Specifications of Modified and Conventional Sugar cane Crushers

Assembly Unit	Parameter	Modified Crusher	Conventional Crusher
Driven Unit	Number of pullies	2	1
	Number of gears	4	2
	Power source	Electric Motor	Diesel Engine
	Required power	12 kW	22 hp
Crushing Unit	Number of rollers	3	3
	Groove's shape	V shape	Rectangular
	Clearance between rollers	0.1 mm	2 mm
	Alignment of rollers	Horizontal	Vertical
	Material	Stainless steel	Cast iron
Collection Unit	Casing	Collector	Metallic sheet
	Type	Closed	Open

In the present study, performance evaluation of conventional and modified sugarcane was conducted under actual field conditions during sugarcane crushing season to determine the method of efficient juice extraction by comparing conventional and modified sugarcane crusher, to get optimized machine elements for extraction of cleaned juice and required improvement in the machine.

2. Materials and Methods

2.1. Experimental Site

Different sites were selected for the

Comparative study and trials of the modified and conventional and sugarcane crushers were performed at different sites located in Punjab, Pakistan, including (i) Shadab Farm Khanewal, (ii) Qureshi Farm, Kotaddu, (30°23'55.4"N 70° 54' 56.8"E) and Khakhi Farm, Shujabad, (30◦07031.1” N, 71°26016.2” E). At these sites, farmers cultivated recommended cultivars of sugarcane. Sugarcane processing was performed using small sugarcane crushers to extract the juice from the cane and make by-products from it.

2.2. Machine specifications

In this study, a diesel engine operated conventional sugarcane and an electric driven modified sugarcane crusher which was developed by AMRI, Multan. The detailed specifications were explained for a better understanding of the working of both the crushers. The overall dimension of the modified sugarcane crusher was 760x600x550 (mm) and its weight was 360 (kg). The specifications of each crusher are described in (Table 1).

2.3. Description of Crusher Components

Both, CC and MC sugarcane crushers, consist of three assemblies i.e., driven assembly, crushing assembly, and juice collection assembly (Fig 1). The juice collection part was open in conventional and closed in modified crusher. The material used for the modified sugarcane crusher was stainless steel, whereas, cast iron was used for the development of the conventional crusher.

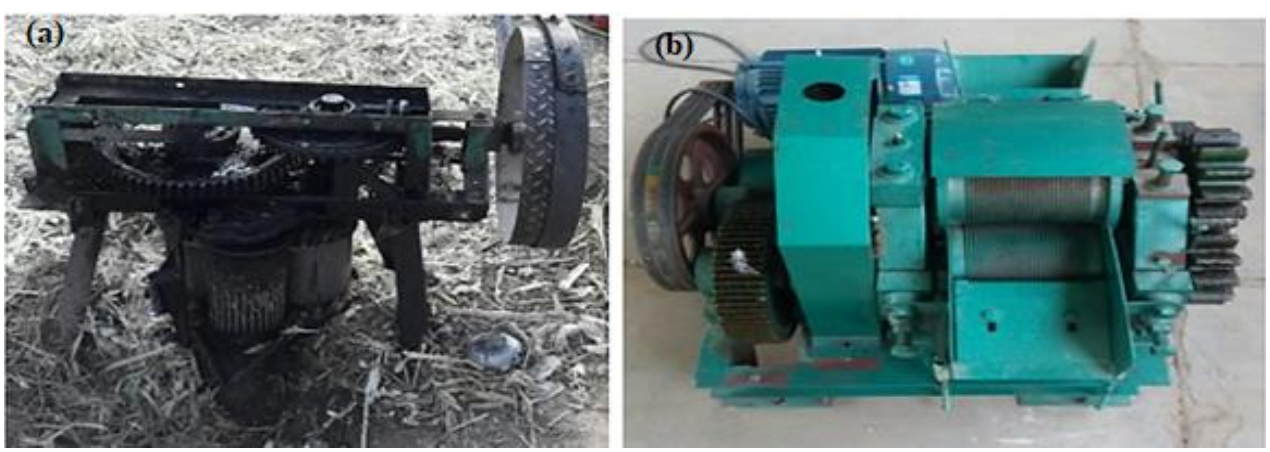

Fig. 1. (a) Conventional Sugar cane Crusher (b) Modified Sugar cane Crusher

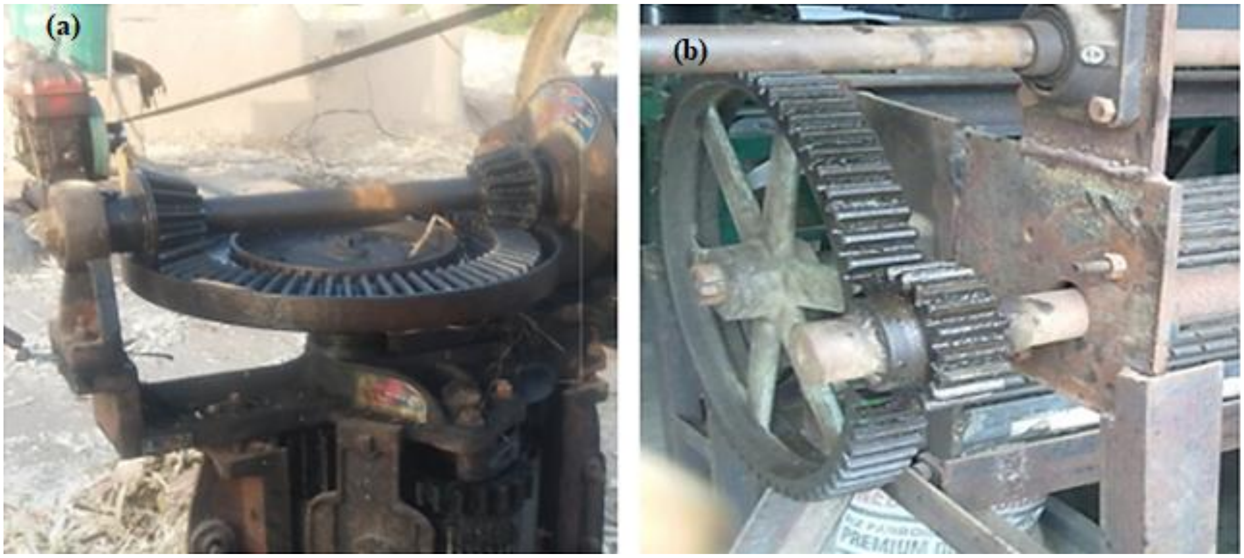

Fig. 2. Driven Assembly of (a) Conventional Sugar cane Crusher (b) Modified Sugar cane Crusher

2.3.1. Driven assembly

The driven assembly contains mostly gears of different sizes and shapes attached with axil and connects the pully with gears to transmit the power to the crushing cylinder. This assembly is used to feed the sugarcane into the machine and transmit it to the crushing assembly for juice extraction. The MC worked with the help of an electric motor. In this crusher, the driving unit consists of two pulleys with four gears and is supplied with a 12-(kW) electric motor. On the other hand, CC consists of one pulley with two gears. This crusher was operated with a diesel engine of 22 (hp) (Fig. 2.

2.3.2. Crushing assembly

The crushing assembly used for juice extraction consists of three crushing rollers in a conventional crusher and two rollers in a modified crusher. In a modified sugarcane crusher, the alignment of rollers was horizontal, whereas, in conventional crushers, rollers were aligned vertically. The shape of grooves in modified machine rollers was V-shaped. On the other hand, in conventional crushers, grooves were rectangular. The purpose for the provision of these grooves on the surface of rollers is to properly grip the sugarcane and apply the crushing force. The clearance between rollers was 0.1 (mm) and 2 (mm) in modified and conventional sugarcane crushers respectively as shown in (Fig 3).

Fig. 3. (a) Modified sugarcane crushing assembly (b) Conventional sugarcane crushing assembly

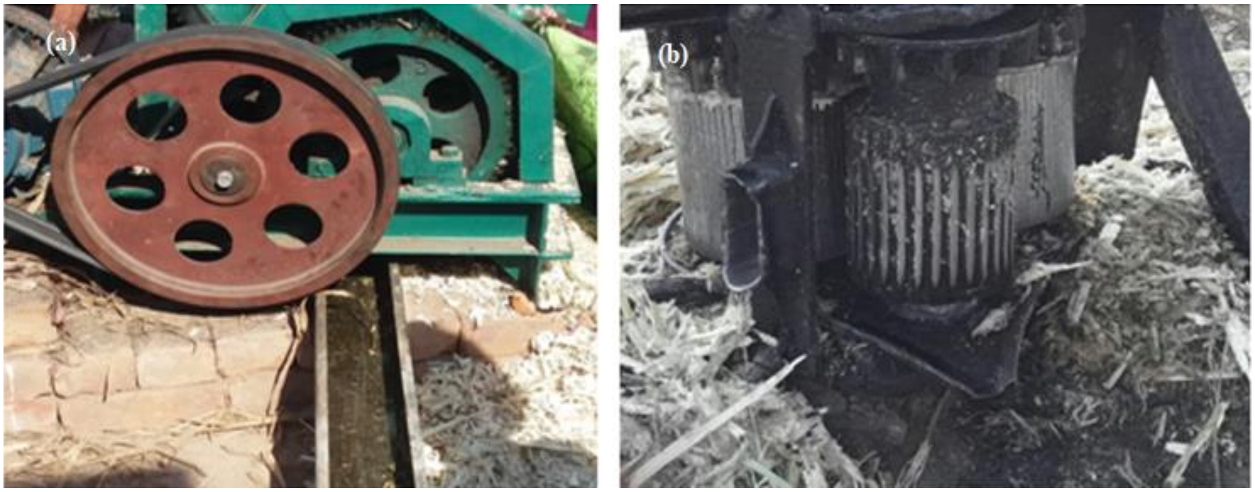

Fig. 4. Juice Collection Mechanism in (a) Modified Sugar cane Crusher (b) Conventional Sugar cane Crusher

2.3.3. Collection assembly

The collection assembly is used to collect the juice extracted from the crushing assembly.

the outlet for the juice, in the conventional sugarcane crushers, is a simple path to direct the juice flow. However, a covered path for the flow of the juice is provided in the modified crushers (Fig 4).

2.4. Experimental Setup

The modified and conventionally developed sugarcane crushers were operated under field conditions to analyze the performance, juice yield, bagasse type, juice extraction capacity, and efficiency. Both the machines were operated at three operating speeds of 790, 1200, and 1420 (rpm) to investigate the impact of speed variations on juice (%) extraction efficiency.

2.4.1. Test Procedure

The testing of both the crushers was carried in actual field conditions. Sugarcane was manually harvested and cleaned. The weight of sugarcane used for test purposes was 50 (kg) for each replication, which was measured in the field with the help of a weighing balance. After starting the machines, the crushing time required for crushing 50 (kg) of Sugarcane, was measured with the help of a stopwatch. Both the machines were operated at the same speed for equal intervals of time. The procedure was repeated 10 times for processing of (50 kg) of sugarcane in each machine. Sugarcane was fed into machines manually and juice extracted was collected into a jar. The bagasse obtained after the processing of sugarcane was collected in polythene bags to measure its weight. After complete processing of sample (50 kg) sugarcane crusher in each machine, noted the time and stop the machines. Then, collected juice and bagasse were weighted. A similar procedure was repeated 10 times for both the machines at two remaining operating speeds.

2.5. Performance Evaluation of the Machine

2.5.1. Extraction capacity

Extraction capacity is the quantity of juice extracted from the sugarcane juice extractor, it can be expressed as:

$$\text{Extraction Capacity (kg}^{-1}) = \frac{M}{T}$$

Where; M and T represents the weight of juice extracted and time used for juice extraction.

2.5.2. Extraction efficiency

The extraction efficiency (%) is the ratio of the juice extracted to the weight of sugarcane, and is calculated as described by Tressler and Joslyn (1961):

$$\text{Extraction efficiency (\%)} = \frac{Je}{F} \times 100$$

Where; J_e, the weight of juice extracted (g); F, weight of sugarcane (g),

2.5.3. Juice yield

Juice yield is the ratio of the juice (weight) extracted to the total weight of wet bagasse, and is calculated as described by Tressler and Joslyn (1961):

$$\text{Juice Yield (\%)} = \frac{Je}{Je+Wr} \times 100\%$$

Where J_e, the weight of juice extracted (g); Wr, weight of residue (g).

Table 2. Experimental Data of Modified Cane Juice Extractor

Speed (rpm)		Extraction Efficiency (%)		Juice Yield (%)		Extraction Capacity (kg h^{-1})		Bagasse Weight (kg)		Time (s)		Moisture Content (%)	
C	M	C	M	C	M	C	M	C	M	C	M	C	M
790	790	45.2	61.0	47.3	67.3	134.0	151.4	25.2	16.3	373	330	2.15	1.09
1200	1200	47.9	68.1	49.2	68.7	136.3	154.7	24.5	15.5	36	323	2.34	1.1
1420	1420	45.2	66.3	46.3	67.8	140.9	165.7	26.2	15.7	355	314	2.7	1.3

C, Conventional juice extractor; M, Modified juice extractor

2.5.4. Moisture content

The amount of water present in the freshly harvested sugarcane stalk is termed as moisture content. In this study, we used moisture content on a wet basis and calculated using the equation below.

Moisture content (%) = M_1-M_2

Where; M_1= Weight of fresh bagasse; M_2= Weight of the dried bagasse

2.5.5. Statistical Analysis

The influence of examined factors (explanatory variables) on the observed (dependent) variables was verified using a two-way analysis of variance (ANOVA). An analysis of variance was performed for each of the following dependent variables: Extraction capacity (kg. hr^{-1}), Extraction efficiency (%), Juice yield (%). Independent variables were crusher operating speed (rpm) and type of sugarcane crusher (i.e., modified and conventional crusher). Both the crushers were operated at three levels of speed (i.e., 790, 1200, and 1420 rpm.

3. Results and Discussion

3.1. Field Performance

The statistical analysis shows that the operating speed and type of crusher significantly affected the dependent variables (extraction capacity, juice extraction efficiency, and juice yield). The interactional effect of operating speed and type of crusher also had a significant ($p \leq 0.05$) influence on the observed variables. The experimental data of bagasse weight and juice extraction (capacity, efficiency, and yield), obtained after the testing of modified and conventionally developed sugarcane crushers are presented in (Table 2). The data was taken 10 times for more accuracy and the means of experimental data was presented in the (Table 2). The detailed comparison of various performance parameters is discussed below sections.

3..2. Comparison of Extraction Capacity

Extraction capacity mainly depends on the time required to process a known quantity of sugarcane. Results of both the sugarcane crushers were obtained through experiments and analyze the data using a statistical model to compare the extraction capacity at three operating speeds of 790,1200 and 1420 (rpm). The highest extraction capacity of the modified crusher was 150.62 (kg/h) when it was operated at 790 (rpm) as shown in (Fig 6).

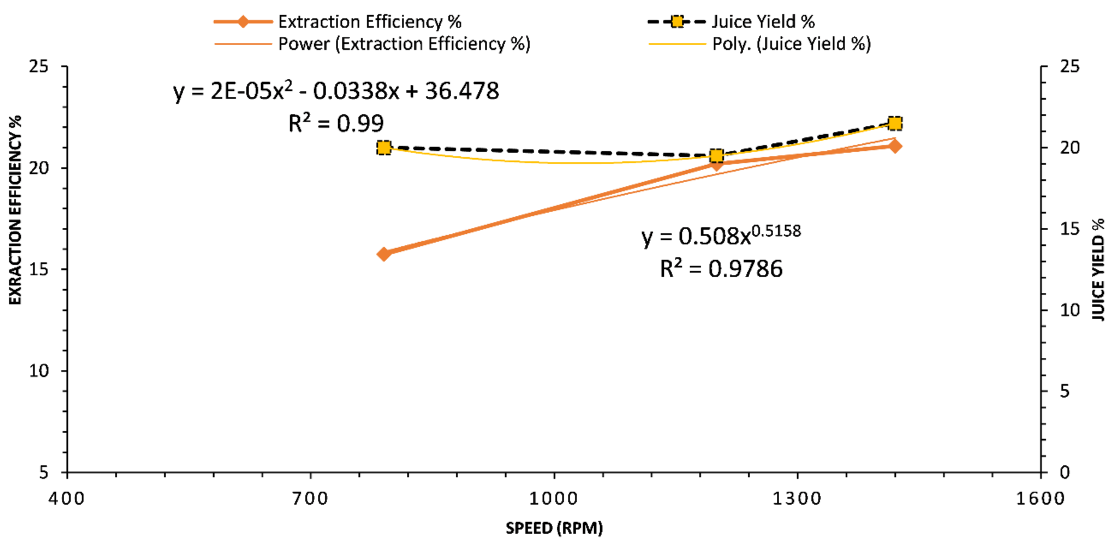

Fig. 5. Graphical representation of Improvement in % Extraction Efficiency and % Juice Yield with modified crusher

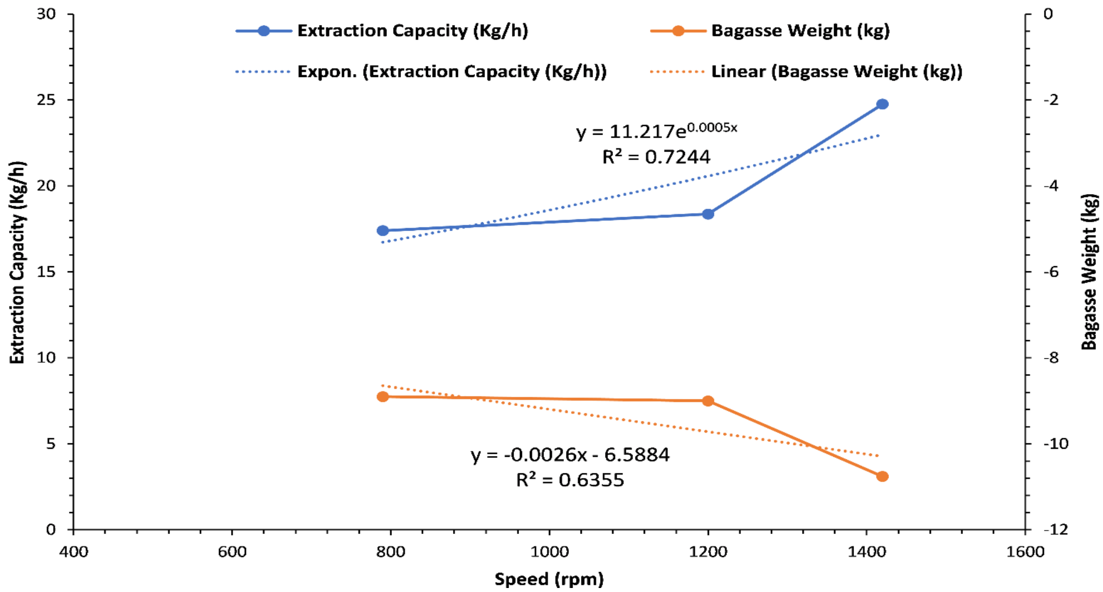

Fig 6. Graphical representation of Improvement in Extraction capacity (kg/hr.) and reduction in bagasse weight (kg) with modified crusher

Whereas, extraction capacity was highest for the conventional sugarcane crusher when it was operated at 1200 (rpm). use the small sugarcane extractor whose extraction capacity is low as 0.38 L/h (Dauda et al. 2017). It was observed that the extraction capacity of the modified sugarcane crusher was higher than the conventional crusher. The extraction capacity of the modified crusher was higher because it takes less time to process the same quantity of sugarcane than the time taken by the conventional sugarcane crusher. The less time was due to the smaller clearance between the crushing rollers. Due to the complex design losses in conventional crushers, it takes more processing time.

3.2. Comparison of Extraction Efficiency

The analysis results, regarding the extraction efficiency, were obtained by the field performance of modified and conventional cane crushers at an operating speed of 790,1200 and 1420 (rpm). From (Table 2), it can be illustrated that the highest extraction efficiency of modified and conventionally developed sugarcane crushers was 66.22 and 47.31 % respectively as shown in Table 2. It was clear that a modified crusher has higher extraction efficiencies than a conventionally developed one as shown in (Fig 5).

As the extraction efficiency is mainly the maximum quantity of juice extracted from a given quantity of sugarcane. The maximum juice extraction is possible only if sugarcane is crushed properly between the rollers and consumes less time. The proper crushing in the modified crusher was mainly possible due to the proper alignment of crushing rollers and proper grip due to optimized grooves on the surface of the rollers. The alignment of rollers in the conventional crusher was vertical which resulted in a poor grip of sugarcane.

3.3. Comparison of Juice Yield

The juice yield expressed in percentage was obtained by statistical analysis of data obtained after field experiments of modified and conventionally developed sugarcane crushers. The obtained results showed that the juice yield of conventional cane crusher at an operating speed of 790, 1200, and 1420 (rpm) was 47%, 49%, and 46% respectively. The results of juice yield for the modified cane crusher at the operating speed of 790, 1200, and 1420 (rpm) were 67, 68, and 67 %, respectively. The percentage of juice yield from modified sugarcane crusher was higher than the conventionally developed crusher as shown in (Fig. 5). This was due to the efficient crushing through rollers that resulted in more sugarcane juice from the modified crusher. On the other hand, juice yield was lower in the conventional crusher due to more clearance spacing between rollers inserting lower crushing force. From the graph, it can be seen that in both types of cane crushers, the juice yield (%) is maximum when the operating speed was 1200 (rpm). Therefore, the optimum speed for the operation of both crushers must be kept at 1200 (rpm) to get the maximum yield of sugarcane juice.

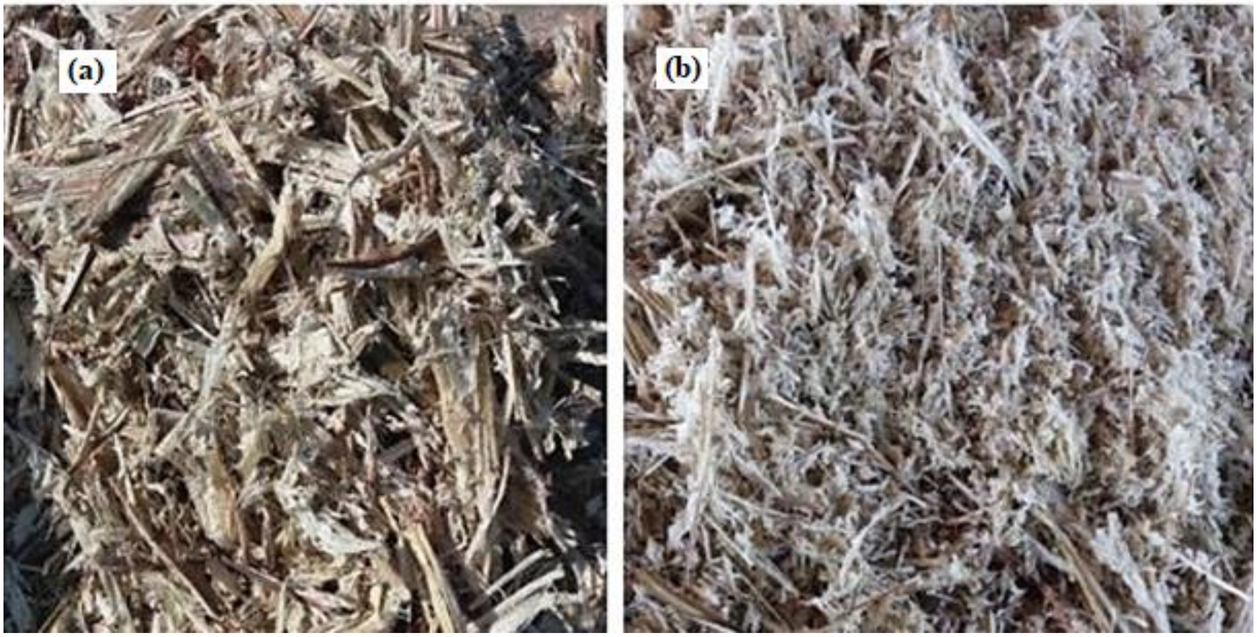

Fig. 7. Comparison of Bagasse Shape Obtained from (a) Conventional cane crusher (b) Modified cane crusher

3.4. Comparison of Bagasse Quality

After the crushing of sugarcane in both the crushers, the waste obtained after processing sugarcane is known as bagasse. The shape of the bagasse was analyzed by observing physically. It was observed that very small particles of bagasse were obtained which shows complete crushing in a modified crusher machine. On the other hand, large particles were observed in bagasse which was obtained from the conventional crusher. The moisture content was higher in bagasse obtained from conventionally developed crusher rather than bagasse from modified crusher as shown in (Fig 6.)

The maximum crushing efficiency can be obtained as a result of the application of more pressing force. The less will be clearance spacing between the rollers, the more force will be applied on the sugarcane stem. This is the reason why the juice extraction efficiency was maximum in the modified sugarcane crusher rather than the conventional crusher. As the intensity of force increases on the sugarcane under processing, the output bagasse was of more fine-shaped particles of a smaller size than the bigger shaped bagasse particles obtained from conventional sugarcane crusher as shown in (Fig 7).

4. Conclusion

The primary objective of the present study was to compare the performance parameters of modified and conventionally developed sugarcane crushers used for the jaggery industry. Both the crushers were tested in the same field conditions to process the same quantity of sugarcane to evaluate their performance at different operating speeds. The statistical analysis was carried out to compare the extraction capacity, extraction efficiency, and juice yield. The analysis results showed that the modified sugarcane crusher performed far better than the conventionally developed crusher. The maximum juice extraction was obtained from a modified sugarcane crusher rather than a conventional one. The moisture content was also lower in bagasse, due to smaller clearance between crushing rollers, obtained from modified sugarcane crusher. The time taken to process (50 kg) of sugarcane was higher in conventional sugarcane crusher due to its improper roller alignment and complex structure. It can be concluded that modified sugarcane crushers are more efficient, safe to operate, and easy to maintain. The juice extracted from the modified crusher is also of a high quality due to its covered structure and corrosion-free material.

Competing Interest Statement: The authors declare that they have no competing interests

List of Abbreviations: ANOVA: Analysis of Variance Technique, CC: Conventional Crusher, MC: Modified Crusher, RPM: Revolution per minute.

Author's Contribution: M.D. planned and conducted the study, collected data, wrote and revised the manuscript under the supervision of F.A. and internship trainer are A.A. and M.I.S., M.T.J., F.A., and S.M. data acquisition, F.A., and A.K. data acquisition and paper formatting. The authors agreed with the content of the paper.

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