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RESEARCH ARTICLE

Improving the extraction efficiency of sugar cane mills using perforated rollers with longitudinal channels

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Abstract

Sugarcane mills are considered special equipment for extracting the sugar solution from the sugarcane plant by applying different pressures and forces to the fibers and bagasse as they pass through the mills. The factories of the Egyptian Sugar Company tended to increase the capacity of the mills to reduce the cost of sugar production, which led to the phenomenon of the juice floating, and this led to a loss of juice due to the bagasse reabsorbing it after it left the mills. In this research, we studied increasing the juice drainage area by changing the mill rollers and producing perforated rollers with longitudinal channels to increase the flow of the extracted juice. This was applied to Czech-made Skoda mills located in Deshna sugar factories. Extraction experiments were conducted on Czech mills with a diameter of 300 mm and a length of 400 mm during the 2023 juice season in Deshna sugar factories. Extraction experiments were carried out on 15 samples of both modified and unmodified mills under the same operating conditions, with a difference in the weight of the samples. The results were positive, as the extraction of the modified mills was better than the extraction of the unmodified mills, with a difference reaching 3.23% when the capacity of the mills was increased to 50%.

Keywords: Extraction Efficiency; Mills; Perforated Rollers; Longitudinal Channels.

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Introduction

The sugar industry is considered one of the important and strategic industries in Egypt, as Egypt is considered one of the countries that is famous for growing sugarcane plants due to the availability of temperature and appropriate soil due to the decrease in the cultivated areas of the sugarcane plant with the increase in sugar consumption rates as a result of the population increase. Countries are working to increase the area under sugarcane cultivation or other sugary plants such as sugar beets to increase the production of white sugar (Shehata et al, 2023; Mehareb 2022).

Among the problems that appear when operating sugarcane mills is the inability to increase the discharge of the extracted juice or corrosion and breakage of the roller teeth or breakage of the roller shafts or breakage of the teeth of the management gears. All of this affects the continuity of operation, decreases the efficiency of extraction, and increases the loss of juice, which in turn leads to a lack of white sugar production, whereas the traditional mill consists of a housing containing three rollers called the feed roller, delivery roller, and top roller, as well as a trash plate and scrapers for both the delivery rollers and the top rollers (Rein and Attard 2007; Singh 2007). Its function is to clean the V grooves of the roller and also the trash plate. Its function is to clean the V grooves of the feed roller, and it is considered a passage for the bagasse from the feed roller to the delivery roller and the cover that contains a hydraulic piston (Santarossa and Swain, 2015). In addition to the hydraulic pressure unit and the central lubrication unit, the more it is possible to operate the mill under ideal conditions in terms of commitment to applying all factors affecting the extraction efficiency, the greater the mill's ability to separate the juice from the cane fibers and the greater the extraction efficiency (Nassr et al. 2020; Bazooyar et al. 2015).

The sugar company's factories increased their capacity to improve their efficiency by reducing the number of days of operation during the juice season to reduce production costs.Win Hsing Company in Taiwan modified the upper roller to a perforated roller instead of the traditional one but did not disclose the date of operation or the results of this modification (Hugot 2014; Kaewpradap and Jugjai 2013). In 1980, Bouvet installed a perforated upper roller due to the lack of Meschert ducts to drain the juice, and he operated it in the final mills in a line with a diffusion device. He revealed that the extraction results improved by a percentage ranging from 2 to 2.5% in the humidity figure, but it was not confirmed if the modification had been made for the first mill or not, as the first mill specializes in extracting the main juice from the fibers without any additions to the spray water, unlike the last mills that extract sugary water from the bagasse after adding the necessary spray water to improve the extraction (Rein 2007).During the juice season at the Deshna Sugar Factory, the phenomenon of juice flotation is observed. This is due to an increase in the amount of cane and thus an increase in the amount of juice extracted with not enough space for the juice to drain. The grooves for draining the juice, whether the Meschert grooves or V grooves are unable to accommodate this extracted juice, which helps in losing the juice in the straw again. In this research, a proposal will be developed to overcome this phenomenon by modifying the three primary rollers of the first mill from the traditional design to the modified one with perforates and longitudinal channels for the two feed rollers, the delivery roller and the top rollers as the modification in each roller has a role in discharging the amount of juice extracted from fibers as the feed and delivery rollers are modified to help overcome the failure to accommodate the V-groove ducts and the Meschert grooves drain excess juice through the holes and longitudinal channels to the main juice basin and the modification to the top roller because this roller does not contain a Meschert groove to overcome the lack of capacity of the juice channels of the V groove in which the adjustment helps to drain the excess amount of juice through the holes and longitudinal channels to the main juice basin. (Hugot 2014; Rien 2007).

Experimental works

In Deshna Sugar Factories, there are two Czech mill lines with diameters of ϕ 300 mm and lengths of 400 mm per roller. The modification was made on only one line, and the implementation stages were as follows: The engineering drawing was made using the AutoCAD program for the typical roller without longitudinal channels, as shown in Figure 1 and the perforated roller with longitudinal channels, as shown in Figure 2. The installation of mill rollers the cast iron shell is prepared as shown in the Figure 3, its condition and its outer and inner diameters are reviewed and an internal lathe is made to ensure the stability of the shell's surface level along the distance of overlap with the shaft and the places for perforating the longitudinal channels are identified and marked as shown in Figure 4, the shaft is prepared and checked for its condition and its outer diameter and an internal lathe is made to ensure the stability of the surface level of the shaft along the distance of the overlap with the shell as shown in the Figure 5, the longitudinal channels are perforated with a suitable punch diameter and length to ensure perforation along the length of the shell to form the longitudinal channels as shown in Figure 6, the oven is prepared for the fitting process by placing the cast iron, charcoal, and wood required for ignition as shown in Figure 7, the oven is ignited for 8 hours until the appropriate expansion for the fitting process occurs and the shaft is placed to form the roller as shown in Figure 8, the external turning work of the roller is completed to reach the required diameter and configuration to form the roller's teeth according to the required pitch and depth (V grooves) as shown in Figure 9.

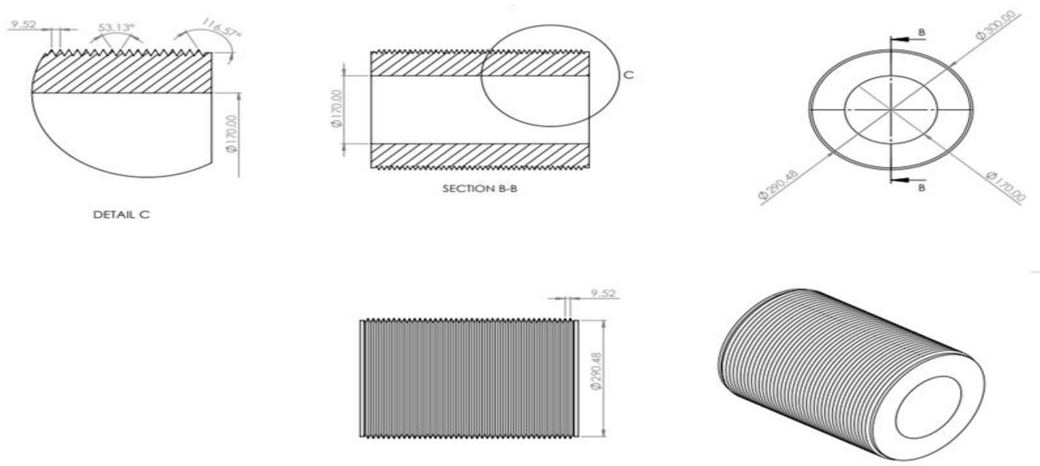

Figure 1. Typical roller without longitudinal channels.

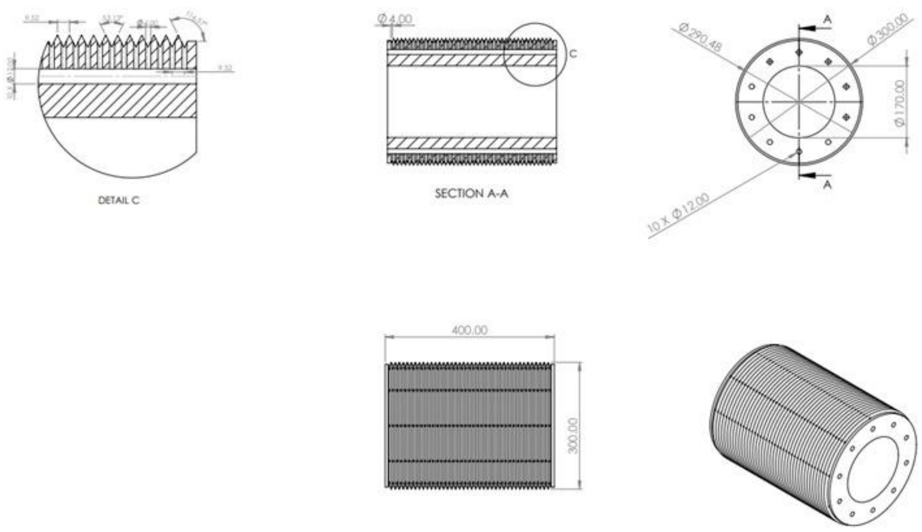

Figure 2. Perforated roller with longitudinal channels.

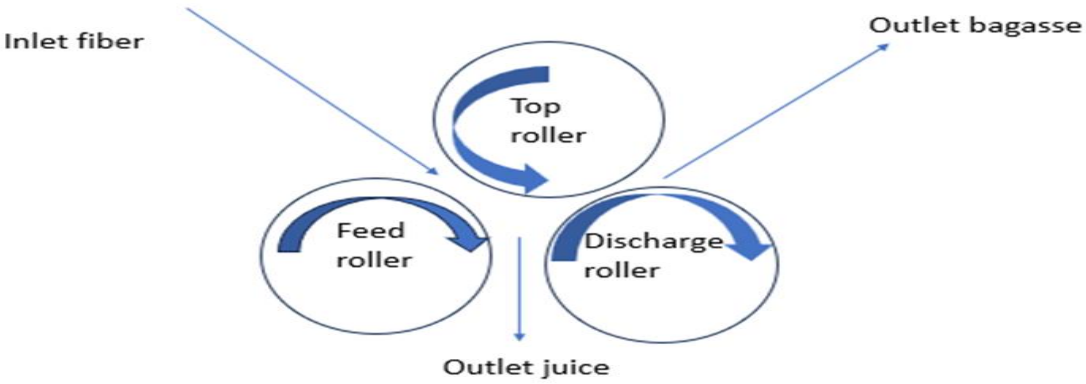

Figure 3. The installation of mill rollers (Deshna factory).

Figure 4. The shaft after lathing (Deshna factory).

Figure 5. The shell after lathing (Deshna factory).

Figure 6. The shell after drilling the longitudinal channels (Deshna factory).

Figure 7. The shell inside the oven before the fitting process (Deshna factory).

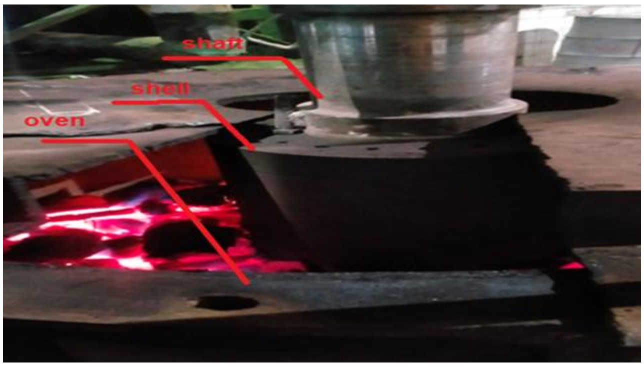

Figure 8. The shell after fitting the shaft to form the roller (Deshna factory).

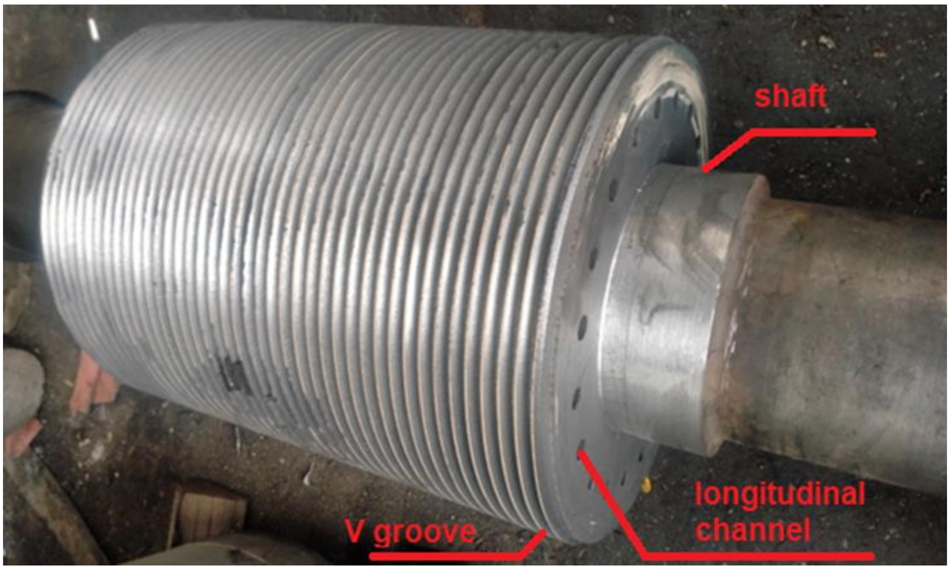

Figure 9. The roller after lathing V grooves (Deshna factory).

A horizontal line is made at the top of each longitudinal channel to determine the location of the perforation, and a vertical hole is made starting from the bottom of each tooth and penetrating into the longitudinal channel with a punch diameter that does not exceed the width of the depth of the tooth to ensure that the shape of the tooth is not distorted as shown in Figure 10.

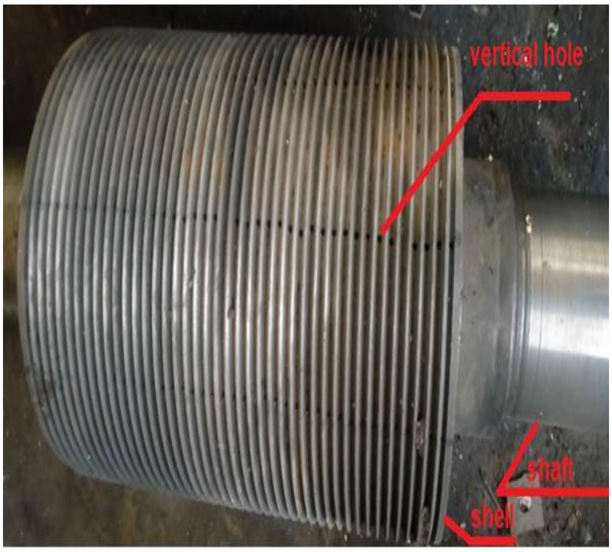

Figure 10. The roller after drilling vertical holes into the longitudinal channels (Deshna factory).

The components of the mill are assembled, the three rollers, the scrapers, and the trash plate are installed, the hydraulic pressure lines and the central lubrication lines are connected, and the mill is run for experiments on empty to review the feed and delivery openings. The mill is stored ready for extraction experiments, as shown in Figure 11.

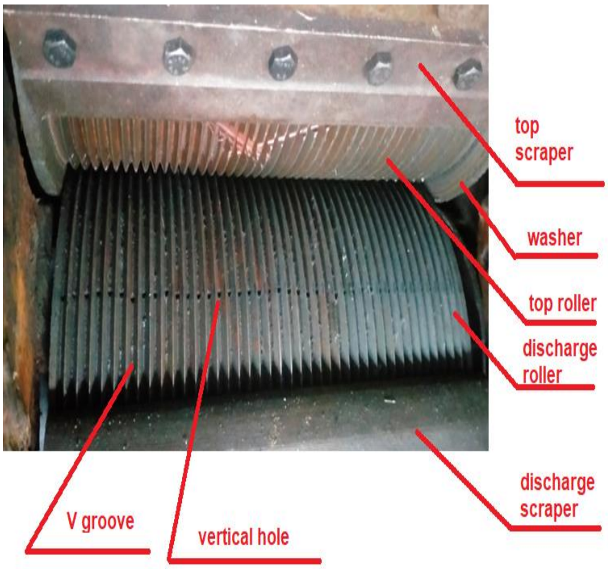

Figure 11. The modified rollers after installation on the mill (Deshna factory).

Results and discussion

In sugarcane mills, different forces are applied to the cane to extract juice from the fibers and bagasse (Elewa et al. 2020).

The higher the degree of preparation, the greater the efficiency of juice extraction (Elkelawy et al. 2022).
It is noted that the phenomenon of flotation of the juice occurs in the primary juice mill of the Dishna factories, which leads to the loss of the amount of juice extracted being reabsorbed again by the bagasse after it exits the mills as shown in Figure 12, and this affects the amount of sugar produced. It was necessary to review the operating conditions of the mills and adhere to all factors affecting the efficiency of juice extraction to obtain the best results. It was studied how to increase the drainage of the excess amount of juice that causes the floating phenomenon, and it was achieved by modifying the design of the mill's roller so that it is equipped with holes and longitudinal channels that allow the excess juice to pass through these holes and then into the longitudinal channels to exit with the rest of the extracted juice into the juice basin (Srichaipanya and Chuan-Udom 2020; Thibane et al. 2023; Hugot 2014).

Figure 12. The phenomenon of flotation in the primary mill of the Dishna factories.

Increasing the surface area for juice drainage was studied to ensure that the bagasse does not reabsorb the juice after it is separated by designing holes and channels in each roller (Shinde et al. 2015). In Egypt, the idea of implementing, installing, and operating the perforated roller was not implemented, despite its need to increase the amount of juice extracted, especially from the primary mill, so that this would help increase the raw material needed for the production of white sugar, Figure 13 shows the isometric perforated with longitudinal channel shell (Deshna factory), and Figure 14 shows the front view section of the perforated with longitudinal channel shell (Deshna factory). Due to the lack of documented extraction results for extracting the primary mill equipped with holes and channels, it was necessary to conduct experiments on two mill lines, one in which the primary mill was modified and the other in which the primary mill was unmodified. Extraction experiments refer to the ability of the mills to separate the sugar solution from the sugarcane plant, and in them, the cane is weighed net before the extraction process and the juice is extracted after the extraction process. The greater the amount of juice extracted, the greater the efficiency of the mills. Extraction experiments were conducted during the 2023 juice season in Dashna sugar factories on two mill lines, one with modified rollers, and the other with unmodified rollers to compare the results. All operating conditions for both mill lines were reviewed, and extraction experiments were conducted under the same operating conditions, taking into account the uniformity of the samples and changing their weights from 20 kg to 30 kg. Table 1 shows all operating conditions for both modified and unmodified mill lines. Extraction experiments were conducted on 15 samples in each mill, and the weights of the cane, the extracted juice, and the extraction percentage by each line were recorded for each sample as shown in Table 2 for the modified mills and 3 for the unmodified mills. It was noted that the shape of the sample reflected the amount of juice inside it and not just its weight; Figure 15 shows the shape of a good sample, and Figure 16 shows the shape of a poor sample. It was also noted that the path of the juice was in the modified mills in each of the longitudinal channels and in the V grooves, as shown in Figure 17, while it was different in the unmodified mills, which were in the V grooves only as shown in Figure 18.

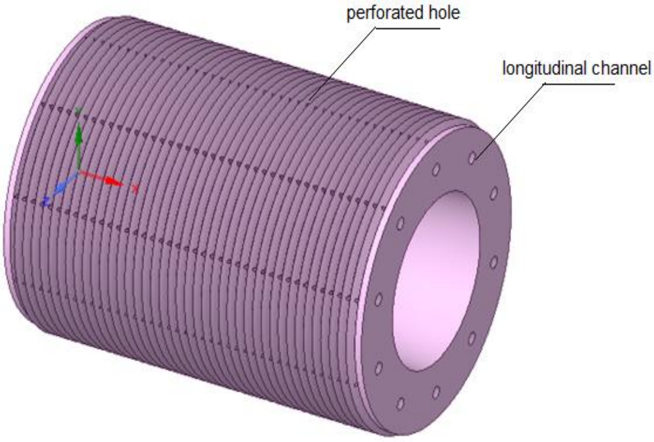

Figure 13. The isometric perforated shell with longitudinal channels (Deshna factory).

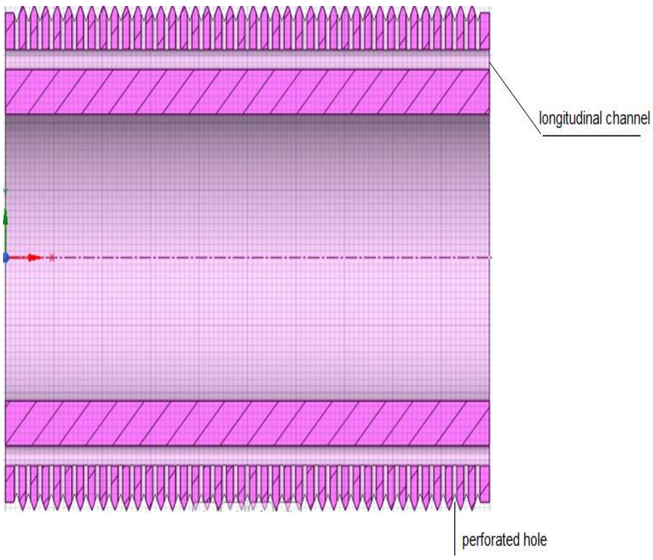

Figure 14. The front view section of perforated with longitudinal channel shell (Deshna factory).

Figure 15. The shape of a good sample (Deshna factory).

Figure 16. The shape of a poor sample (Deshna factory).

Figure 17. The path of the juice in the modified mills in each of the longitudinal channels and in the V-grooves

(Deshna factory).

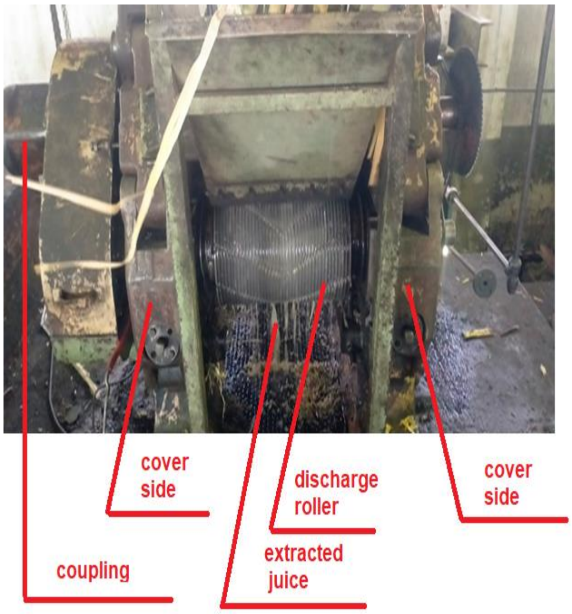

Figure 18. The juice path in unmodified mills is in the V grooves only (Deshna factory).

Table 1. The operation conditions for both modified and unmodified mills (Deshna factory).

M	STATEMENT	DATA
1	1st mill pitch/depth feed roll	
2	1st mill pitch/depth top roll	9.52 / 8 mm
3	1st mill pitch/depth delivery roll	
4	1st mill opening (Inlet/outlet/knife)	4/2/20mm
5	2nd mill pitch/depth feed roller	
6	2nd mill pitch/depth top roller	9.52 / 8 mm
7	2nd mill pitch/depth deliveryroller	
8	2nd mill opening (Inlet/outlet/knife)	2/0/14 mm
9	1st&2nd mill power/speed	18.5 kW / 975 rpm
10	1st&2nd mill reduction ratio	250: 1
11	1st&2nd mill mills speed	3.9 rpm / 9.18 m / s
12	1st&2nd mill Hydraulic pressure	220 bar

Table 2. The results of extraction experiments for modified mills (Deshna factory).

M	1st LINE MODIFIED MILLS		
	Net weight of sugar cane (kg)	Net weight of juice (kg)	Extraction ratio(%)
1	20.050	13.07	65.19
2	20.125	13.14	65.30
3	20.139	13.19	65.49
4	20.164	13.24	65.66
5	20.198	13.36	66.15
6	25.025	16.95	67.73
7	25.065	17.02	67.90
8	25.115	17.08	68.01
9	25.142	17.17	68.29
10	25.177	17.57	69.79
11	30.033	21.02	69.99
12	30.074	21.08	70.10
13	30.123	21.16	70.25
14	30.149	21.26	70.52
15	30.191	21.33	70.66

Table 3. The results of extraction experiments for unmodified mills (Deshna factory).

M	2nd LINE UNMODIFIED MILLS		
	Net weight of sugar cane (kg)	Net weight of juice(kg)	Extraction ratio(%)
1	20.040	12.66	63.17
2	20.095	12.72	63.30
3	20.130	12.75	63.34
4	20.155	12.79	63.46
5	20.185	12.85	63.66
6	25.010	16.19	64.73
7	25.050	16.24	64.83
8	25.095	16.28	64.87
9	25.120	16.35	65.09
10	25.160	16.73	66.50
11	30.015	19.77	65.87
12	30.055	19.79	65.85
13	30.095	19.82	65.86
14	30.125	19.90	66.06
15	30.175	19.93	66.05

Figure 17 shows the relationship between the results of sugarcane weights and its extraction rate in the modified and unmodified mills.

Factors affecting the results of extraction experiment

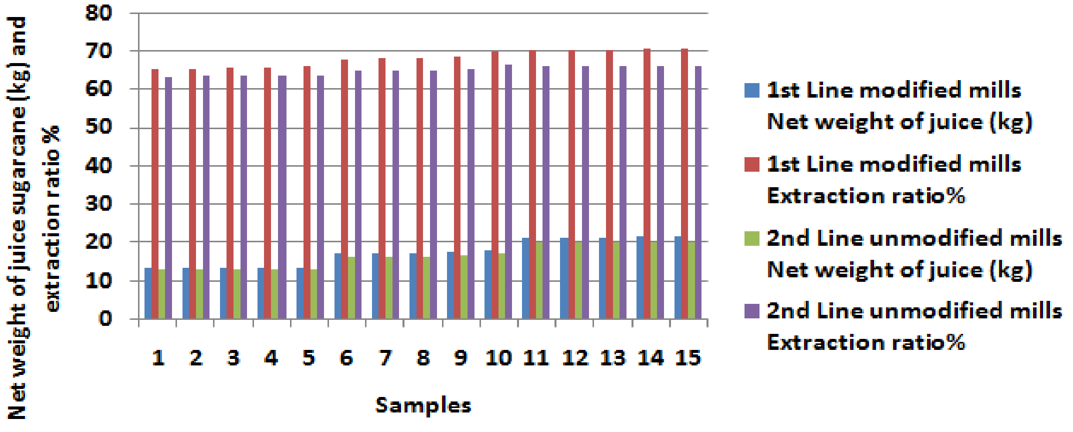

Figure 17. The relationship between the results of sugarcane weights and its extraction rate in the modified and unmodified mills (Deshna factory).

Cane quality

By simply looking at the cane samples, one can judge the quality of the cane in terms of the availability of the sugar solution inside it, regardless of the amount of sugar inside the sugar solution. From the cane samples, there are good samples with a high sugar solution and there are samples with the same weight but with a low sugar solution (Birkett et al. 1987). Good samples were used in the extraction experiments. Many extraction experiments have been carried out, and it was noted that the cane with a good shape gives more sugar solution at the same weight, regardless of the sugar content inside the sugar solution. This may be due to the difference in the quality of the cane and the extent of the farmer's interest in the method of cultivation, the irrigation process, and the period of storage until the pressing process.

Hydraulic pressures.

One of the important factors that affects the efficiency of extraction is hydraulic pressure. The greater the hydraulic pressure that affects the mills, the greater the extraction efficiency. 15 extraction experiments were conducted on both modified and unmodified mills under the same conditions, both at a pressure of 200 bar and 220 bar. The extraction experiments for both mill lines at a pressure of 220 bar were better than operating at a pressure of 200 bar by a percentage that ranged from 2 to 4%. The hydraulic pressures during the extraction experiments for both lines were 220 bar.

Rotational Speed

The speed of the mills is considered one of the factors affecting the extraction efficiency of the mills. The lower the speed, the greater the extraction efficiency, and vice versa, the faster the mills, the less the extraction efficiency. The speeds of the mills range between 4-6 rpm (Lewinski et al. 2011). The speed of the mills was constant during the extraction experiments of the research subject, which was 3.9 rpm (9.18 m / s).

Capacity

The mill capacity is one of the main factors in improving the mill extraction efficiency, as the higher the mill capacity, the greater the mill extraction efficiency (Sembada 2017).

Extraction experiments were conducted on 5 weights of 20 kg on each of the two lines, and the extraction efficiency of the modified mills was better than the extraction efficiency of the unmodified mills by 2.49%. Then, the capacity of the mills was increased, and extraction experiments were conducted on 5 weights of 25 kg, with an increase of 25% on the two lines of mills. The extraction efficiency of the modified mills increased over the efficiency of the unmodified mills by 3.29%. Then extraction experiments were conducted on 5 weights of 30 kg. By 50% on the two lines of mills, the extraction efficiency of the modified mills increased by 4.61% over the extraction efficiency of the unmodified mills.

Mill settings

Mill settings are considered among the factors that include important sub-factors, which are the pitch and depth of the roller teeth, the diameter of the roller, the feed and delivery, and the trash plate openings. The greater the pitch of the roller the lower the efficiency of extracting mills and vice versa the smaller the pitch of the roller the greater the efficiency of extracting mills. The depth of the roller pitch is made in proportion to the roller pitch and according to the results of the extraction efficiency (Gnanavadivelu et al. 1990; Garson 2019).

The pitch and tooth depth of the roller teeth during the extraction experiments were 9.52 x 8 mm. As for the feed and delivery openings, the smaller they are, the greater the extraction efficiency. The delivery opening is considered a proportion of the feed opening, and the delivery opening is from 1/2 to 1/3 in the first mill and reaches 1/5 in the last mill. The extraction experiments on the feed and delivery openings were as follows: 4/2 mm for the first mill and 2/0 mm for the last mill. For the trash plate, it is considered a passageway for the bagasse from the feed roller to the delivery roller, and it uses its teeth to clean the feed roller V grooves (Nassr et al., 2020; Bazooyar et al. 2015).

As for the value of the opening, it represents the smooth shape of the surface of the trash plate, which helps to withdraw the mill, and it was obtained during the extraction experiments as follows: 20 mm for the first mill and 14 mm for the last mill.

Technical expertise

Technical expertise plays a major role in the efficiency of extracting mills in terms of the good operation of the mills and avoiding problems and malfunctions that may occur and cause the mills to stop (Nassr et al. 2020; Wienese 1995; Kim and Day 2011; Gonçalves et al. 2021).

Modifying the perforated roller instead of the solid one by making holes and longitudinal channels to increase juice drainage. Table 4 shows the difference between a perforated roller and a solid roller in terms of: the extent of replacement and change, reliability, durability, functionality, capital cost, maintenance, financial return, operating life, operating problems, manufacturing, extraction, humidity, and sugar loss.

Table 4. The difference between a perforated roller and a solid roller

M	Statement	Solid roller	Perforated roller
1	The extent of replacement and change	It can be replaced or changed instead of the perforated roller.	It can be replaced or changed instead of the solid roller.
2	Reliability	Traditional design	Modern design
3	Durability	High	High
4	Functionality	Less juice drainage	More drainage of juice
٥	Capital cost	Low	Medium
٦	Maintenance	Easy and low cost	Complex and moderate cost
٧	Financial return	Low	High
8	Operating life	5 years	5 years
9	Operating problems	Nothing	Nothing
10	Manufacturing	Easy	Complex
11	Extraction	Low improvement	High improvement
12	Humidity	Low improvement	High improvement
13	Sugar loss	Low improvement	High improvement

Whereas for the extraction of mills at a weight of 20 kg, the extraction of the modified mills was from 65.19 to 66.15%, while the extraction of the unmodified mills was from 63.17 to 63.66%. After increasing the weights of the samples to 25 kg, the extraction of the modified mills ranged from 67.73 to 69.79%, while the extraction of the unmodified mills ranged from 64.73 to 66.50%. After increasing the sample weights to 30 kg, the extraction of the modified mills ranged from 69.99 to 70.66%, while the extraction of the unmodified mills ranged from 65.87 to 66.05%, with an average modified mill extraction of 68.07% and an average unmodified mill extraction of 64.84%. Comparing the results of extraction experiments from the extraction curve for both modified and unmodified mills, the extraction of modified mills is better than the extraction of unmodified mills, as shown in Figure 18.

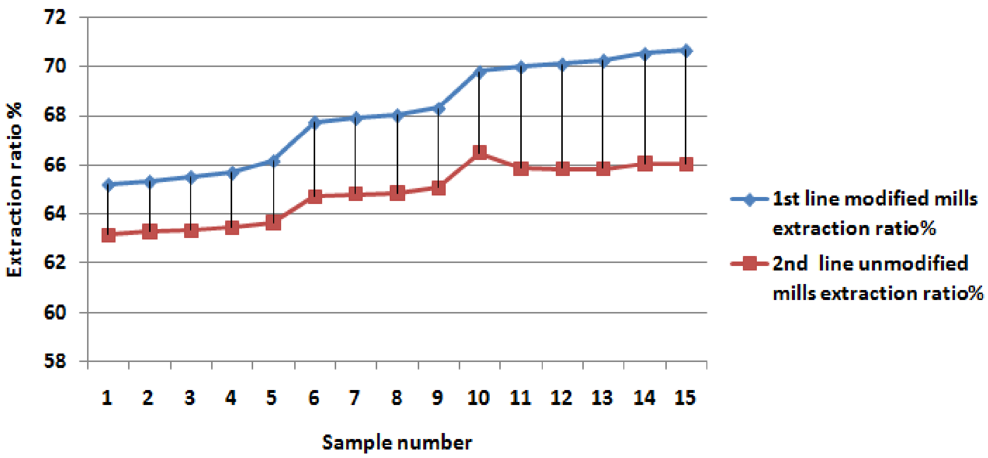

Figure 18. The extraction curve for both modified and unmodified mills (Deshna factory).

Conclusions

The extraction of the modified mills was much better than the extraction of the unmodified mills due to the good drainage of juice through the holes and longitudinal channels after extraction and the absence of the floating phenomenon as the bagasse was not absorbed by the juice after leaving the mills. This helped to reduce the loss of sugar in the bagasse and increase the amount of raw main juice, as when weighing at 20 kg, the extraction of the modified mills was higher than that of the unmodified mills, with a difference of up to 2.49%. By increasing the capacity of the mills to 25 kg, the extraction of the modified mills was higher than that of the unmodified mills, with a difference of up to 3.29%. By increasing the capacity of the mills to 50%, the extraction of modified mills was higher than the extraction of unmodified juices by a difference of 4.61%, and the difference in the average extraction of modified mills compared to unmodified mills increased by 3.23%.

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