

Research Article

Microfluidization-Driven Changes in Some Physicochemical Characteristics, Metal/Mineral Composition, and Sensory Attributes of Sugarcane Juice

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Received 26 August 2021; Accepted 22 November 2021; Published 8 December 2021

Academic Editor: Muhammad Imran

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This work evaluated the effect of microfluidization at different pressure (50, 100, 150, and 200 MPa)-cycle (1, 3, 5, 7) combinations on the physicochemical (total soluble solids, titratable acidity, pH, and electrical conductivity), sensory, and metal/mineral composition of sugarcane juice which was previously unexplored. Juice extracted from blanched sugarcane stems (var Co 0238) was microfluidized, and the analysis for different parameters was conducted using standard protocols. The mineral/metal composition was determined using ICP-OES following a wet digestion method. Results showed that TSS decreased from 18.88 °Brix to a range of 10.15–15.7 °Brix with the former (lower value) being due to the release of insoluble matter after microfluidization which was further solubilised at higher processing cycles (as in the latter). The pH did not vary significantly as compared to control and was in the range of 5.2–5.7. However, a decrease in titratable acidity (0.1–0.26%) was found as compared to control (0.26%). The electrical conductivity of microfluidized sugarcane juice varied from 4.45 to 5.12 mS as compared to 4.95 mS for control. Metal/mineral analysis showed rich reserves of magnesium, phosphorus, potassium, and calcium in sugarcane juice which degraded after microfluidization perhaps due to filtration effect caused by the micropore in the interaction chamber of the microfluidizer. The sensory score showed acceptability of the juice after microfluidization (overall acceptability ~7).

1. Introduction

Microfluidization is an emerging liquid and semisolid food processing technique that has gained popularity in the food sector. It is a high-pressure processing technology that works on the principle of high-shear force generation with occasional cavitation through a microchannel of fixed geometry. Microfluidization is now extensively used for emulsification, particle size reduction, enzymatic inactivation, and microbial destruction [1–3]. The effect of microfluidization on the quality characteristics of different juices has been investigated that includes mango and goji juice [4], yam juice [5], jujube juice [6], peach juice [7], seabuckthorn juice [4], Ottoman strawberry juice [8], and carrot juice [9], among

others. Due to its tremendous potential for juice preservation, it is now being considered as a viable option for beverage processing unit operations.

Sugarcane juice is another plant-derived beverage which is relished in tropical climates as a thirst-quenching drink with numerous health benefits. However, sugarcane is not available throughout the year, and its juice is very difficult to process and preserve due to its high sugar composition which promotes yeast and bacterial growth. Fortunately, the effect of microfluidization on the quality characteristics of sugarcane juice has been investigated in previous studies [10–12] which helped establish the fact that the technology can be used effectively for juice preservation to some extent. However, the effect of microfluidization on the

physicochemical characteristics of sugarcane juice such as titratable acidity, pH, electrical conductivity, and metal/mineral composition has not been reported yet. Moreover, the sensory attributes of sugarcane juice as affected by microfluidization has also not been evaluated, to the best of our knowledge. Therefore, this work aims to analyze the effect of microfluidization on the physicochemical, metal/mineral, and sensory characteristics of sugarcane juice over a wide range of processing conditions (pressure/cycle combinations) to fill the identified knowledge gap.

2. Materials and Methods

2.1. Material Procurement and Processing. Freshly harvested mature sugarcane stems (var. Co 0238) were procured from a local farm of Kashipur (29.2115°N, 78.9692°E), Uttarakhand (India). Stems of diameter 2.5 ± 0.9 cm were washed and cut into 0.45 m long pieces. The cut pieces were then blanched in hot water at 95°C for 5 min. After blanching, the stems were retrieved from the water bath and immediately cooled under running water ($25 \pm 3^\circ\text{C}$) for 2–3 min. The excess water on the stems was wiped clean using a piece of cotton cloth, and the stems were then kept for 30–60 min at room temperature prior to juice extraction. A twin roll mechanical crusher was used for juice extraction. The crusher was cleaned with distilled water and wiped with a sterilized cotton cloth prior to the extraction process. The extracted juice was filtered using two-layered muslin cloth to remove particulate matter. The collected juice was kept under refrigeration and processed within 10–15 min.

Sugarcane juice was processed using a laboratory-scale microfluidizer equipped with a Y-type diamond interaction chamber with a 75 μm channel (M 110–P, Microfluidics, Corporation, Newton, MA, USA). Microfluidization pressure was varied as 50, 100, 150, and 200 MPa, while the number of microfluidization cycles was varied as 1, 3, 5, and 7. Untreated juice was taken as control.

2.2. Determination of Total Soluble Solids. Total soluble solid (TSS) content was measured using a digital refractometer (Model RX-7000i, Atago, Japan). The sample chamber of the equipment was washed with Milli-Q water and wiped clean before analysis. The equipment was calibrated with Milli-Q water at 25°C. Sugarcane juice (2–3 drops) was then placed in the sample chamber, and the results were recorded in oBrix. The sample chamber was cleaned with Milli-Q water between consecutive sample measurements to ensure that there was no trace of the earlier sample.

2.3. Titratable Acidity and pH. Titratable acidity was determined using the method of Singh et al. (2012) with minor modifications [13]. Twenty millilitres of diluted sugarcane juice sample (1:10 with Milli-Q water) was reacted with 0.1 N NaOH in the presence of phenolphthalein indicator (1–2 drops). End point was identified by the occurrence of a light pink color in the reaction mixture with the addition of base. The percentage acidity was expressed in citric acid equivalence as

$$\% \text{titratable acidity} = \frac{\text{Volume of NaOH used} \times \text{normality of NaOH} \times \text{equivalent weight of citric acid}}{1000 \times \text{volume of sample titrated}} \times 100. \quad (1)$$

The pH of the control and microfluidized sample was determined using a calibrated digital pH meter (CyberScan EU TECH, Thermo Fischer Scientific, India) with an uncertainty of ± 0.1 . The pH meter was washed with Milli-Q water and wiped clean before and after sample measurement.

2.4. Determination of Electrical Conductivity. Electrical conductivity was measured using a portable water analyzer (Model 371, Systronics, India) equipped with a 1.0 K probe (range 0.01–100 mS/cm). The equipment was calibrated using KCl solutions of 0.1 M (12.88 mS/cm), 0.01 M (1.41 mS/cm), and 0.001 M (0.146 mS/cm) concentrations prior to measurements. All measurements were carried out at 25°C. Results were expressed in milli Siemens per centimeter (or mS/cm).

2.5. Determination of Metal/Mineral Composition by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). Sugarcane juice samples for metal/mineral analysis were prepared using the wet digestion method [14] with

minor modifications [15]. Approximately 0.4–0.5 g of sample was taken in a 50 mL beaker. 1 mL of hydrogen peroxide was added to the sample for oxidation. The sample was digested using 5 mL of concentrated nitric acid (69%) with constant heating at 70°C in a water bath. Digestion was continued for 1.5–2 h till attainment of a pale yellow color. The digested sample was transferred to a 50 mL volumetric flask, and the volume was adjusted to 50 mL using Milli-Q water. Metal/mineral composition in sugarcane juice was determined using a Perkin Elmer ICP–OES (Optima 7000 DV, USA). A multielemental standard was used for analysis of metals and minerals. The equipment was calibrated using different concentrations of the standard (5, 10, 25, 50, and 100 ppb) in 5% HNO_3 . Reference blank was taken as diluted HNO_3 (5%). Analysis was carried out in triplicates. Results were expressed as the elemental mineral present in mg/mL of sugarcane juice.

2.6. Sensory Evaluation of Microfluidized Sugarcane Juice. Sensory evaluation was conducted using a 9-point hedonic scale with a panel of 29 semitrained members (13 males + 16 females) comprising faculty members and students of

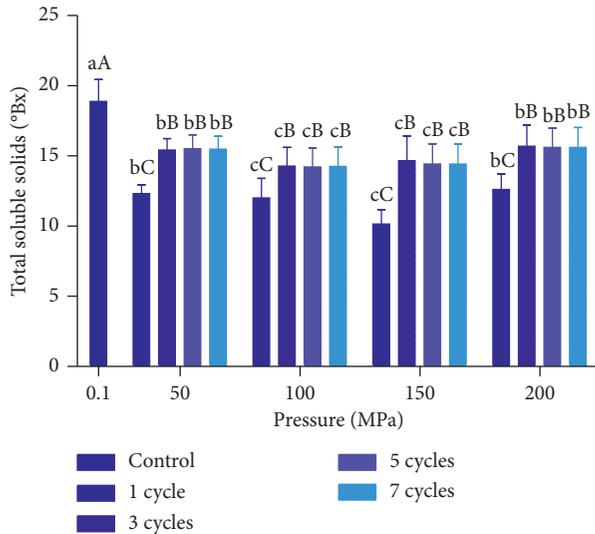


FIGURE 1: Effect on total soluble solids with microfluidization.

NIFTEM, Sonipat (India). The panelists were in the age group of 17–35. The scorecard was prepared and given to each panel member to evaluate the attributes of the fresh and processed juice in terms of color, aroma, sweetness, taste, and overall acceptability. The panel members were seated away from each other under constant ambient conditions. They were asked to rinse their mouth with water between consecutive samples. It was also ensured that no panel member was suffering from any cold or fever or was, in any way, organoleptically challenged.

2.7. Statistical Analysis. All experiments were performed in triplicates, and the analysis of dependent parameters was conducted at least in duplicates. The results were expressed as mean \pm standard deviation. ANOVA and Duncan's multiple-range test (post hoc analysis) were conducted in SPSS v.20 software (IBM, USA) at 5% significance level.

3. Results and Discussion

3.1. Effect on TSS. The TSS of control was estimated as 18.88 ± 1.58 °Brix which was concomitant to that of reported literatures. A significant decrease in TSS was observed after microfluidization ($p < 0.05$) that varied in the range of 10.16 ± 1.03 to 15.71 ± 1.49 °Brix. Denaturation of enzymes in the juice as a result of pressure treatment could be associated with the decrease in TSS [8].

The reduction in TSS with microfluidization is in contradiction to the results observed during high-pressure processing of sugarcane juice, probably due to the nature of pressure augmentation in the two technologies. In the first cycle of processing, lower TSS was observed at all microfluidization pressures (Figure 1) which increased at higher processing cycles. This change could be due to higher extent of particle size reduction and release of any insoluble solids from the particles for multiple shearing actions. Increasing the number of cycles to three, five, and seven increased the TSS, but there was no significant difference in TSS within

these cycles ($p > 0.05$). This shows that three passes is sufficient for complete mass transfer from the juice particles and further solubilisation in the surrounding medium.

3.2. Effect on pH and Titratable Acidity. The pH of control was determined as 5.55 at 25°C and did not vary significantly with microfluidization pressure and cycles ($p > 0.05$). The pH of the microfluidized sample was observed in the range of 5.21–5.79 (Figure 2(a)). In contrast, titratable acidity varied with both microfluidization pressure and the number of cycles ($p < 0.05$). The percentage titratable acidity for control was observed as 0.26%. After microfluidization, the titratable acidity varied in the range of 0.10–0.26% with no specific trend in data (Figure 2(b)). At the first cycle, an increasing-decreasing trend was observed, while at the third cycle, no significant change in acidity was observed till 100 MPa pressure with highly reduced acidity at 150 MPa pressure.

At the second cycle of processing, there was slightly increased acidity at pressures of 150 and 200 MPa. At the third cycle, the acidity at 150 MPa decreased significantly following which there was an abrupt increase at 200 MPa. At the fourth cycle, the acidity increased upto 150 MPa pressure and then decreased again at 200 MPa. Overall, the pressure/cycle combination of 150 MPa/7 cycles and 200 MPa/3 cycles was able to maintain the natural acidity conditions of sugarcane juice.

3.3. Effect on Electrical Conductivity. The electrical conductivity (EC) of control was observed as 4.95 ± 0.20 mS and varied in the range of 4.45 ± 0.34 to 5.12 ± 0.10 mS with microfluidization (Figure 3). EC of the microfluidized sugarcane juice varied significantly with pressure ($p < 0.05$) but not with the number of cycles ($p > 0.05$). At pressures higher than 100 MPa, the electrical conductivity was observed to be relatively higher and comparable to that of control. Formation of ions in sugarcane juice due to high pressure and cavitation could lead to an increase in EC.

3.4. Effect on Metal/Mineral Composition. Control and microfluidized samples exhibited substantial amounts of magnesium, phosphorus, potassium, and calcium with trace amounts (< 0.05 mg/mL) of lead and manganese (Table 1). The presence of lead could be due to heavy-metal-contaminated irrigation water used for cultivation of the sugarcane crop. Degradation of metal/mineral content was observed with microfluidization.

The maximum degradation of 42.85% in Mg, 38.69% in P, 18.99% in K, 58.83% in Ca, and 39.13% in Mn was observed with microfluidization of sugarcane juice. From the results, it can also be seen that calcium and magnesium are the most susceptible minerals to high-pressure microfluidization. The reduction in minerals in general could be due to the pore size of the microchannel in the microfluidizer that could have restricted the minerals from moving out. There was also a 46.42% reduction in Pb content

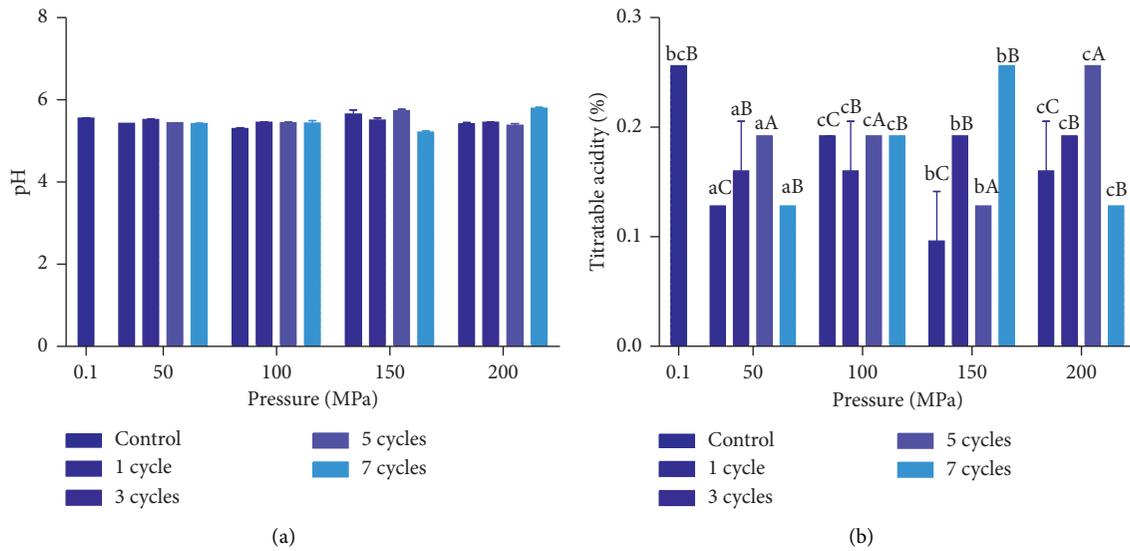


FIGURE 2: Effect of microfluidization on (a) pH and (b) titratable acidity. Post hoc test was not applied on pH values as ANOVA was found nonsignificant.

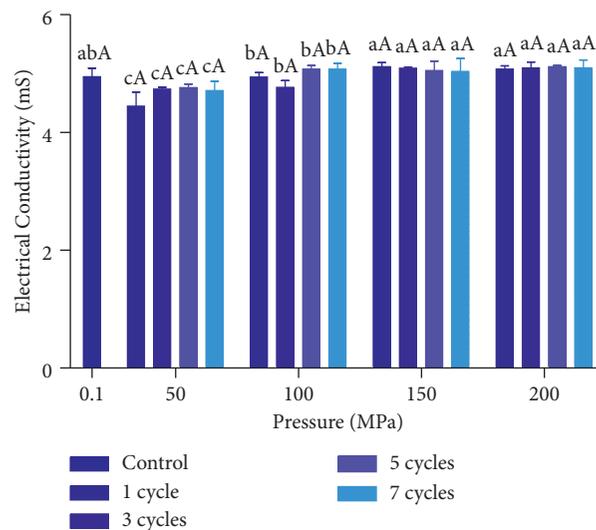


FIGURE 3: Electrical conductivity of control and microfluidized sugarcane juice. Small-case letters represent the effect of pressure, while capital-case letters represent the effect of passes. Datasets with different letters differ significantly at 5% level of significance by Duncan's multiple comparison test.

which shows that microfluidization could have applications in heavy-metal removal.

3.5. Analysis of Sensory Characteristics. The sensory profile was judged on the basis of color, aroma, sweetness, taste, and overall acceptability of the control and microfluidized sugarcane juice (Table 2). The color of the control was scored as 7.2, while the score of microfluidized juice ranged from 6.8–7.7 indicating color retention in sugarcane juice after processing, from a subjective viewpoint. The aroma score of control was 7.4, while the score of microfluidized juice varied from 6.7–7.8. The aroma score was lower for all processing conditions except at 150 MPa/1 cycle showing

retention of aroma at this processing condition. The sweetness of control was scored as 7.1 and received a slightly higher score for the processed juice at 100 MPa/1 cycle, 150 MPa/1 cycle, and 150 MPa/7 cycle. Higher sweetness could be an indication of conversion of sucrose to reducing sugars such as fructose and glucose [12]. The taste score of sugarcane juice varied from 6.8 to 7.4 with 7.2 for control. Although the highest score was observed at 200 MPa/1 cycle; the processing condition showed lower scores for other sensory characteristics. Taking into account higher color, aroma, sweetness, and overall acceptability score of sugarcane juice processed at 150 MPa/1 cycle, it could be considered a viable processing condition from a sensory standpoint.

TABLE 1: Metal and mineral composition (in mg/L) of control and microfluidization sugarcane juice.

Processing conditions	Mg	P	K	Ca	Pb	Mn
Control	2.728	1.274	2.395	2.009	0.028	0.023
50/1 cycle	2.422	1.213	2.234	1.929	0.012	0.022
50/3 cycles	1.955	1.131	2.267	1.559	0.019	0.020
50/5 cycles	1.559	0.781	2.429	0.827	0.015	0.012
50/7 cycles	1.616	0.887	2.195	1.102	0.016	0.019
100/1 cycle	1.857	0.937	2.361	1.172	0.018	0.014
100/3 cycles	2.001	1.040	2.111	1.263	0.017	0.020
100/5 cycles	2.214	1.043	2.342	1.424	0.017	0.018
100/7 cycles	2.209	1.033	2.392	1.601	0.017	0.018
150/1 cycle	2.340	1.108	2.354	1.616	0.016	0.020
150/3 cycles	2.191	1.117	2.045	1.551	0.015	0.019
150/5 cycles	2.060	0.984	1.949	1.310	0.018	0.017
150/7 cycles	1.987	1.123	1.940	1.878	0.020	0.020
200/1 cycle	2.339	1.245	2.303	2.013	0.021	0.020
200/3 cycles	2.212	1.058	2.314	1.733	0.018	0.016
200/5 cycles	2.133	1.209	2.270	1.400	0.015	0.018
200/7 cycles	2.200	1.216	2.011	1.582	0.016	0.017

TABLE 2: Sensory characteristics of control and microfluidized sugarcane juice.

Processing condition	Color	Aroma	Sweetness	Taste	Overall acceptability
Control	7.2 ± 0.9	7.4 ± 0.9	7.1 ± 1.2	7.2 ± 0.9	7.2 ± 1.2
50 MPa/1 cycle	7.3 ± 1.0	7.1 ± 1.1	6.9 ± 1.1	7.2 ± 1.0	7.1 ± 0.9
50 MPa/3 cycles	7.2 ± 1.0	7.1 ± 0.9	6.8 ± 1.1	7.0 ± 1.0	6.9 ± 0.9
50 MPa/5 cycles	6.7 ± 1.5	7.2 ± 1.1	7.0 ± 1.0	7.1 ± 0.8	7.1 ± 0.9
50 MPa/7 cycles	6.9 ± 1.0	6.7 ± 0.9	6.7 ± 1.3	6.8 ± 0.9	6.8 ± 1.0
100 MPa/1 cycle	7.3 ± 0.9	7.2 ± 0.9	7.4 ± 0.9*	7.3 ± 0.9	7.1 ± 0.8
100 MPa/3 cycles	7.2 ± 1.1	7.0 ± 0.8	6.9 ± 1.2	7.1 ± 0.9	6.9 ± 1.0
100 MPa/5 cycles	7.0 ± 0.9	6.8 ± 1.0	6.9 ± 1.0	7.0 ± 0.9	6.9 ± 0.9
100 MPa/7 cycles	6.9 ± 1.3	6.8 ± 1.3	7.1 ± 1.0	6.9 ± 0.8	6.9 ± 1.1
150 MPa/1 cycle	7.7 ± 0.9*	7.8 ± 0.8*	7.4 ± 0.8*	7.3 ± 0.9	7.4 ± 0.8*
150 MPa/3 cycles	7.1 ± 1.1	7.2 ± 0.9	6.7 ± 1.1	6.9 ± 1.3	6.6 ± 1.2
150 MPa/5 cycles	7.1 ± 1.2	7.1 ± 1.3	6.9 ± 1.3	7.3 ± 0.9	7.2 ± 1.1
150 MPa/7 cycles	6.9 ± 1.2	7.3 ± 1.2	7.2 ± 0.7	6.9 ± 1.3	6.9 ± 1.5
200 MPa/1 cycle	7.1 ± 1.1	7.3 ± 1.1	7.0 ± 1.0	7.4 ± 0.9*	7.1 ± 1.0
200 MPa/3 cycles	6.9 ± 1.5	6.8 ± 1.4	7.1 ± 1.4	7.2 ± 0.9	6.9 ± 1.6
200 MPa/5 cycles	7.1 ± 1.3	6.9 ± 1.0	6.7 ± 0.8	6.9 ± 1.1	6.9 ± 1.5
200 MPa/7 cycles	6.8 ± 1.1	6.8 ± 0.9	6.5 ± 1.2	7.0 ± 1.0	6.4 ± 1.3

*Highest value of each sensory parameter.

4. Conclusions

Microfluidization significantly influences the physico-chemical characteristics of sugarcane juice with minimal effect on the sensory attributes. No significant effect was found on the pH which shows that pH adjustment of sugarcane juice for preservation may be accompanied with microfluidization. Based on the results, it can be inferred that pressures higher than 100 MPa but lower than 200 MPa could yield high-quality sugarcane juice with better nutritional properties. The influence of microfluidization on the functional properties of sugarcane juice through *in vivo* methods is warranted.

Data Availability

All data pertaining to this work are provided in the article.

Conflicts of Interest

The authors declare no conflicts of interest with respect to this work.

Acknowledgments

The authors thank the Vice-Chancellor of the National Institute of Food Technology Entrepreneurship and

Management, Kundli, Sonipat for his support in conducting this work. The first author thanks UGC for providing senior research fellowship, letter no. F1-17.1/2017-18/RGNF-2017-18-SC-RAJ- 37149.

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