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Evaluation of clarification process of Indonesia's sweet sorghum juice by ultrafiltration membrane and the physicochemical and sensorial properties of the sugar product

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Abstract

The juice derived from *Sorghum bicolor* L. exhibits a notable sugar content, rendering it a promising candidate for use as a sweetening agent. The presence of impurities in sorghum juice encompasses several substances such as non-sugar molecules, non-fermentable reducing agents, starch, and minerals like salt, magnesium, and calcium. The objective of this study was to investigate the impact of ultrafiltration (UF) membranes on the physicochemical properties of sorghum juice and sugar granules, as well as to identify customer preferences for these products. The study consisted of three primary phases. The first phase involved investigating the impact of 0–3 cycles of UF treatment on the physicochemical properties of the sorghum juice. The second stage involved comparing the characteristics of sugar granules obtained through UF and non-ultrafiltration (non-UF) methods. The third one focused on examining the preference of sorghum sugar granules in their natural state and as a sweetener for steeped black tea. A 5% significance level was employed in this work to conduct multivariate methodology of variance and the Friedman nonparametric test. The findings of the study indicate that the use of UF treatment has a simultaneous impact on the turbidity and color of sorghum juice. Non-UF sorghum sugar granules exhibit a superior aroma in comparison to UF granules while maintaining identical color, taste, and texture. Consumers exhibited a preference for steeped black tea sweetened with palm sugar, followed by rock sugar, granulated sugar, UF sorghum sugar granules, and non-UF.

Keywords: sorghum juice; sugar granules; ultrafiltration membrane; sensory properties.

Practical Application: The ultrafiltration membrane serves as an advanced instrument for clarifying sorghum juice in small-scale production. This device can also be used to clarify other sugar juices, such as palm, coconut, and sugarcane.

1 INTRODUCTION

The increasing demand for sugar as a sweetening agent in the food and beverage industry in Indonesia can be attributed to the changing patterns of public consumption. Previously, sugarcane served as Indonesia's primary crop utilized as a primary source for sweeteners. Indonesia's sugar demand has reached 6 million tons annually despite the country's total sugar production being just 2.2 million, as reported by the Ministry of Industry of the Republic of Indonesia in 2021 (Kemenperin, 2022). The recorded figure experienced a 5.9% increase in 2020, reaching a total of 975.6 tons, marking the most significant growth in the preceding five years (Kemenperin, 2022). Notwithstanding the augmented production, it is imperative for cane sugar production to align with the nation's demands. From 2016 to 2019, Indonesia's annual sugar imports exceeded 4 million metric tons. Considering this, it is imperative to explore alternative sources of sweetener raw materials, apart from sugarcane plantations, to meet the nation's sugar demands and decrease dependence on imported sugar.

Sweet sorghum, the stems of which can produce sugar, is one type of plant that can be used as a sweetener source. Sweet sorghum (*Sorghum bicolor* L.) is a grain crop with significant development potential in Indonesia because of its extensive environmental adaptation, particularly on marginal dry land. Sorghum is another alternative commodity for food and feed with a lot of potential due to all the biomass components that may be used. However, this plant has yet to be widely and optimally farmed to become a commodity with economic worth comparable to other crops. Because of its high water and sugar content, sweet sorghum has the potential to be employed as a sugar-producing plant. According to Tsuchihashi and Goto (2004), the sugar content of sweet sorghum stalks is relatively high (76–78%), with the comparable sugarcane level reaching 68–80%. Based on this, sweet sorghum can be a potential candidate for the sugar industry.

Sugar derived from sorghum juice and sugarcane juice are, in general, identical. Ayustaningwarno et al. (2023) and Vu et al. (2020) asserted that fresh juice is tainted with impurities,

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including non-sugar substances, non-fermentable reducing agents, starch, and minerals (e.g., sodium, magnesium, and calcium) that are sizable enough to dissolve in the sorghum stem skin and impart a murky hue to the juice (Ali et al., 2018). Prior to this juncture, the sugar industry in Indonesia encountered substantial challenges, including substandard product quality, low productivity, and exorbitant production expenses. The outcome has been a decline in the effectiveness and competitiveness of domestic sugar.

Several studies have investigated various methods for purifying sorghum juice. These methods include different clarifying agents and heat temperature (Harlen & Ristiarini, 2023), enzymatic purification using dextranase as described by Eggleston and Triplett (2017), the application of sodium metabisulfite as explored by Ali et al. (2019), a combination of heat temperature and adsorbents as examined by Ali et al. (2018), the utilization of coagulants such as $Ca(OH)_2$ and MgO as investigated by Costa et al. (2015), and the implementation of chitosan gel and pH regulation in sorghum juice purification as proposed by Bilal et al. (2017).

The membrane is a thin layer between two phases of fluid, namely the feed phase and the permeate phase. It functions as a barrier to a specific species and can separate substances of different sizes and limit different species based on their physical and chemical properties (Chibrikov et al., 2022). The membrane is semipermeable, allowing it to retain certain species with higher dimension size than the pore size while allowing other species with lower dimensions to pass through (Vu et al., 2020). This membrane's selective properties can be utilized in the separation process. This technique is frequently employed to separate colloids and reduce the concentration, purification, and fractionation of macromolecules such as proteins, pigments, and other polymeric substances. The separation process in membrane technology occurs at room temperature, can be performed continuously, varies in nature, and can be tailored to specific requirements. Ultrafiltration (UF) membranes are presently widely used in food processing.

To date, investigations into the use of UF membranes to purify juice have primarily focused on sugarcane juice, as exemplified by the studies undertaken by Suprihatin (2007) and Vu et al. (2020). The juice clarifying experiment involved sugarcane juice circulation for 180 min. The juice was circulated at a flow rate (v) of 0.42 m/s, and three pressure levels (p) were applied: 0.7, 1.4, and 2.1 bar. This experiment followed the crossflow principle, as described by Suprihatin (2007). The process can enhance the transparency of juice, resulting in a transmission clarity ranging from approximately 10–60%. It also has the potential to significantly reduce the intensity of color by about 80–90%. The resulting juice exhibits a pH level within the range of 5.4–6.0, a Brix measurement between 8.6 and 10.1%, a polarity ranging from 7.6 to 9.9%, a color intensity between 2.242 and 13.614 International Units, and a transmission clarity of 56–65%.

Consequently, the present investigation was to investigate the impact of UF membranes on the physicochemical properties of sorghum juice and sugar granules, as well as to identify customer preferences for these products.

2 MATERIALS AND METHODS

2.1 Materials

Sweet sorghum stems (*Sorghum bicolor L. Moench*), cv. Bioguma, harvested between 80 and 90 days after cultivation from Bandung, West Java, Indonesia, were used. Other materials used were sucrose, CaO, aquadest, and reagents for analysis.

Equipment used includes a sugarcane milling machine, an open pan evaporator (Oxone), a Buchner funnel (Buchi), a booster pump 24V DC type DP-A-050 (Tianjin Daehwa), pressure gauge bar units, filter cloths, a ¼-in RO hose, valve type straight L 1/4-in, a ¼-in stop valve, clamps, stative, fitting type straight L T 1/4 in, blue Araldite glue, PVC scissors, stem connector type straight L T 1/4 in, scales, a beaker (Iwaki), aluminum foil, plastic, dark bottles, funnels, filter paper, and hotplate stirrers. The apparatus used for analysis includes an Erlenmeyer petri dish, a test tube, a colorimeter (Hunter's Lab Colorimetric System), a UV-vis spectrophotometer, a refractometer (ATAGO), and a pH meter (Hanna). UF membrane (oxfil) specification used was 10-inch length, 4-inch diameter, 50 ntu feed turbidity, 0.1 ntu permeate turbidity, and 0.3 MPA max feed.

2.2 Experimental procedures

This study comprises three primary phases. This study aims to investigate the impact of UF on the characteristics of sorghum juice. The UF intensity factors considered in this study are 0, 1, 2, and 3 cycles. The sorghum juice was then measured for pH, color, total dissolved solids, turbidity, viscosity, total sugar content, and total acid. Furthermore, this study also examines the sugar granules produced from UF and non-ultrafiltration (non-UF) processes. The physical and chemical properties of sugar granules included yield, color, wettability, solubility, bulk density, tap density, flowability, moisture content, ash content, total sugar content, protein content, fat content, and total calories. The last study includes a sensory evaluation of sorghum sugar as granules and as a sweetener in black tea drinks.

The statistical methodology employed in this study was multivariate methodology of variance and the Friedman nonparametric test. These analyses were conducted using the Statistical Package for Social Science application, specifically version 26.0. A significance level of 5% was chosen for determining statistical significance.

2.3 Sorghum juice preparation

The juice from the sorghum stem was extracted mechanically using a rotary drum mill or sugarcane press. Before extraction, the sorghum stems are cleaned of leaves and dirt that are still attached and then cut into pieces 30 cm in size. The sorghum stems were then placed in the feed part of the extractor to be pressed, and the extract yield was calculated based on the volume units (Ali et al., 2018).

Sorghum juice was conventionally filtered using filter cloths with a mesh size of ± 100 mesh. The resulting sorghum juice was measured in volume first using a measuring cup. The filtered juice was then analyzed for the initial characteristics, including pH, color index (L*, a*, b*), viscosity, total dissolved solids (% Brix), turbidity, total sugar content, and total acid.

2.4 Sorghum juice ultrafiltration

Filtration treatment was performed using a developed UF device. The device consisted of a ¼-in hose, a ¼-in valve, a ¼-in stem connector, a booster pump, a pressure gauge, a ¼-in UF membrane housing (pre-made), a stative, clamps, and a beaker (Figure 1). The inlet of the booster pump related to the ¼-in hose until the feed container beaker was reached. The pump outlet was associated with the ¼-in hose made into two branches. The first branch was connected to the permeate container, while the second branch was transmitted directly to the feed container. Each unit was joined by a ¼-in valve. After the samples were ready, the pure water was recirculated for about 1 hour before distributing the sorghum juice. Before UF treatment, sorghum juice was pre-treated by filtering it with filter paper and was stored at ambient temperature to reduce the burden on the UF membrane performance. The pre-treated samples were circulated in the UF membrane circuit according to Figure 1. UF treatment was carried out until permeate was obtained. The permeate from the first circulation was used as feed for the second circulation, and the second permeate was used as feed for the third circulation. The UF-treated sorghum juice was then analyzed, including pH, color index (L*, a*, b*), viscosity, total dissolved solids (% Brix), turbidity, total sugar content, and total acid (Ali et al., 2019; Harlen & Ristiarini, 2023).

2.5 Sorghum sugar granule production

Because sorghum juice has an acidic pH, a 10% CaO solution was required to neutralize the juice. The homogenization process was conducted by means of a magnetic stirrer. The sample was subsequently concentrated. After adding 30% (w/v) sucrose into neutral sorghum juice, the mixture was heated and agitated at 100–120°C until thickened. A concurrent experiment was conducted wherein the sample thickened juice was submerged in water; if the dough solidified, the heating procedure was halted. A continuous kneading motion was maintained until the dough underwent crystallization.

The sugars were subsequently dehydrated for 1.5 h at a temperature of 50°C to decrease the residual moisture content. The granulated sugar was further pulverized to get a homogeneous and even consistency. Subsequently, the sugar granules were carefully enclosed within a hermetically sealed plastic bag prior to examination. The properties of the sugar granules of sorghum under each treatment were then analyzed. The sugars in their granulated form were further examined for their color and solubility (Harlen & Ristiarini, 2023) and proximate compositions (Fauziyah et al., 2022).

2.6 Sensory evaluation

A hedonic test was carried out by 35 semi-trained panelists (Fauziyah et al., 2024). The panelists evaluated the color, aroma, taste, and texture of the granulated sorghum sugar. Subsequently, they assessed the color, aroma, taste, and after-taste of five different sugars in black tea drinks. The five sugars were granulated sorghum sugar non-UF, granulated sorghum sugar UF, granulated palm sugar, crystal cane sugar, and lump sugar. Each hedonic test was done on a scale of 1–7, namely:

(1) strongly dislike;

(2) dislike;

(3) slightly dislike;

(4) neutral;

(5) slightly like;

(6) like;

(7) like very much (Fauziyah et al., 2024).

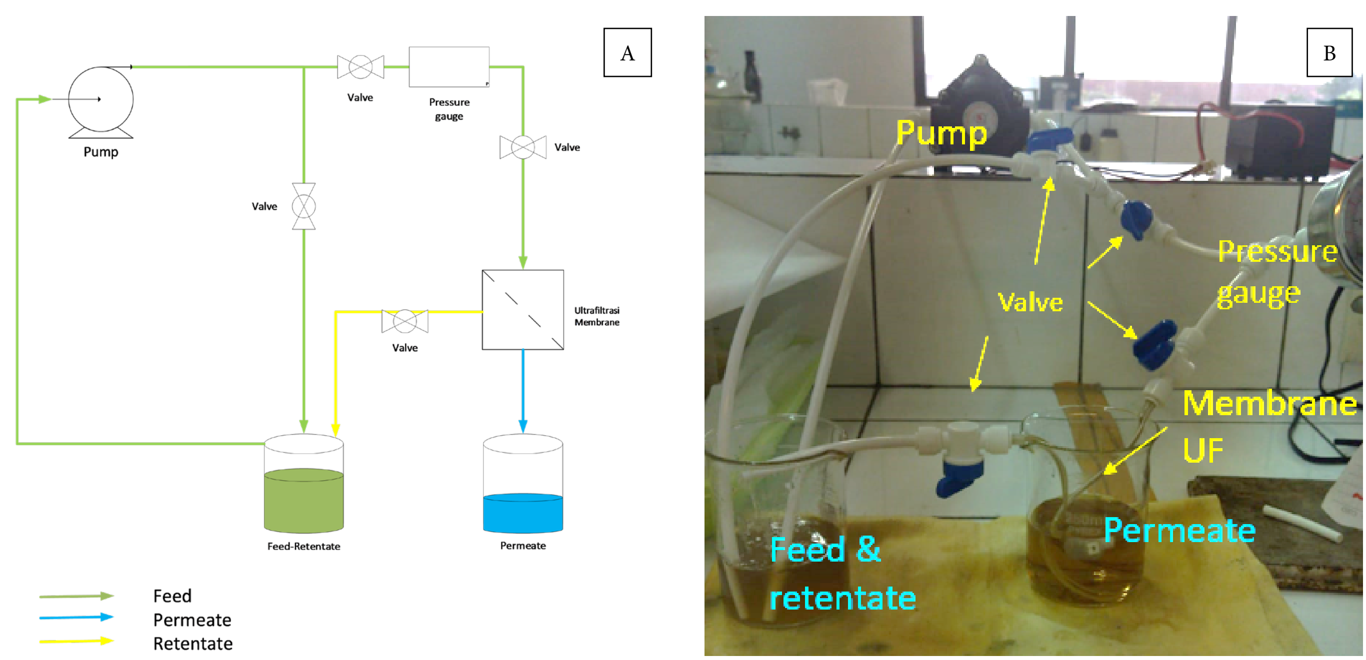


Figure 1. (A) Schematic and (B) actual ultrafiltration membranes for sorghum juice clarification.

Each granulated sorghum sugar was individually manufactured in a tagged container containing both UF and non-UF samples for the preference test. To conduct the preference test as a sweetener, a total of five containers were prepared with 1 liter of hot water. Subsequently, tea bags were brewed in each container for a duration of 3 min. Subsequently, an additional five sweeteners, each weighing 60 g, were incorporated into the mixture. These sweeteners included non-UF and UF of granulated sorghum sugar, crystal cane sugar, lump sugar, and palm sugar.

3 RESULTS AND DISCUSSION

The initial characteristics of sorghum juice in this experiment are presented in Table 1. In general, the quality of juice extracted from sorghum stems varies greatly depending on the type of plant, age, planting conditions, and harvesting time according to Ali et al. (2018).

3.1 Effect of UF and Non-UF on sorghum juice characteristics

Figure 2 depicts the visual characteristics of sorghum juice prior to and following UF treatment. Non-UF sorghum juice exhibits a cloudy dark green appearance, but ultrafiltered sorghum juice displays a clear green coloration, typically displaying transparency.

The UF treatment influenced the overall concentration of dissolved solids in sorghum juice. Total dissolved solids tended to decrease in all UF treatments. It was postulated that the membrane's surface and pores harbored solute constituents such as starch and phosphate. Therefore, it can be observed that the particle size of the solution closely matches the pore size range of microfiltration membranes, which typically falls within the range of 0.05–10 μm (Vu et al., 2020). The reduction in overall dissolved solids can be attributed to the utilization of filters that effectively bind suspended materials within water.

Table 1 demonstrates the range of total dissolved solids, and it was demonstrated that the sorghum juice exhibited a range of total dissolved solids, varying from 12 to 13.9%. The observed results exhibited a modest decrease compared to the Brix value reported in earlier studies, which ranged from 12.3 to 17.4%. According to Reny Sjarif et al. (2021), the Brix degree of total dissolved solids refers to the dry solids that are dissolved in a solution (g/100 g solution). These solids are determined by calculating the concentration of sucrose and other solids.

Table 2 demonstrates that the L*, a*, and b* values of sorghum juice were influenced by UF treatment in relation to its color qualities. There was only a difference in the L* value of sorghum juice between the non-UF and UF treatment groups. After UF, the L* value in sorghum juice exhibited a tendency to drop. The visual findings of the investigation exhibited an inverse relationship. The study conducted by Kailaku et al. (2016) yielded comparable results; however, variations in the attributes of raw material composition and harvesting conditions could potentially lead to disparities in L* values.

Table 2 shows that the turbidity of sorghum juice was influenced by UF treatment. There was a significant difference observed between the UF and the non-UF juice. This was due to the presence of several contaminants in freshly extracted sorghum juice, necessitating a purification procedure to eliminate them and yield transparent sorghum juice (Sasaki et al., 2017). The decrease in turbidity observed following the UF process can

Table 1. Physicochemical characteristics of sorghum juice.

Properties	Sorghum juice	References
Yield (%)	35.71	40[1]
Total dissolved solids (% Brix)	13.90 ± 0.14	11.60 ± 0.35[2]
Color index		
L*	41.87 ± 0.01	32 ± 0.32[2]
a*	–3.31 ± 0.01	–2.2 ± 0.15[2]
b*	6.81 ± 0.03	8.57 ± 0.49[2]
Turbidity (absorbance)	4.73 ± 0.09	1.77 ± 0.01[3]
Viscosity (cp)	3.19 ± 0.01	2.0 ± 0.58[2]
pH	5.30	5.5[3]
Total sugar (%)	34.11 ± 3.74	12.93[3]
Total acid (meq NaOH/g)	0.010 ± 0.002	–

Source: [1]Noerhartarti and Rahayuningsih (2013); [2]Harish Rahman and Yuwono (2019); [3]Ali et al. (2018).

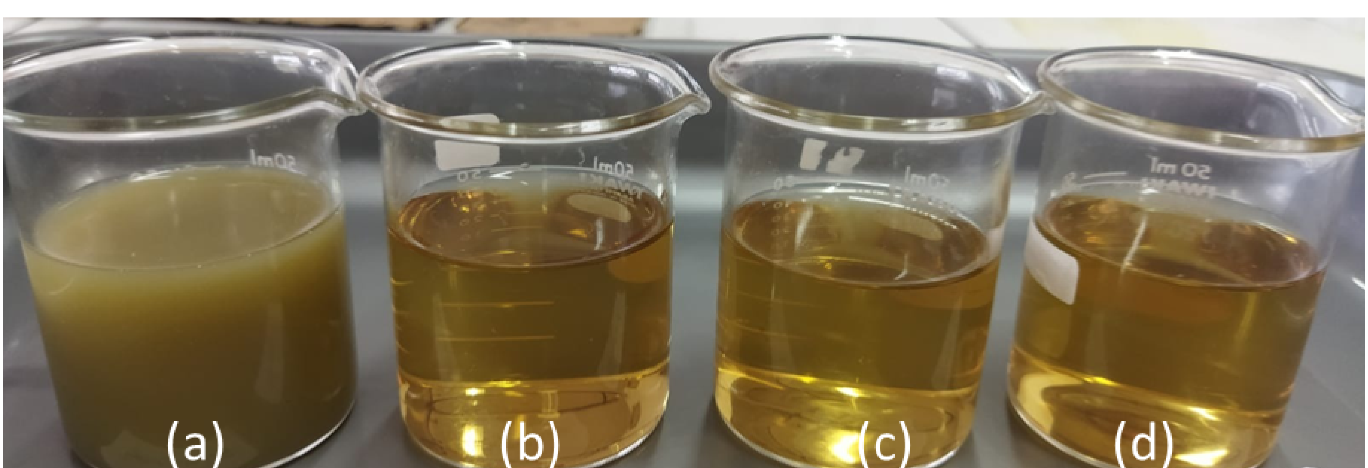


Figure 2. Sorghum juice: (A) non-UF, (B) once UF, (C) two times UF, and (D) three times UF.

be attributed to the impact of holes on the membrane. According to Susanto et al. (2013), it has been observed that the clarity and color reduction of the resultant sugar solution are influenced by the size of the membrane pores.

The viscosity of sorghum juice was similarly influenced by the UF treatment. There was a significant difference observed in the treatment of non-UF, 1× UF, and 2× UF compared to the 3× UF treatment (Table 2). According to Vu et al. (2020), the determination of a product's viscosity value is contingent upon the overall quantity of solids that are dissolved inside the product. As the total solids dissolved in a product rise, the viscosity also increases, resulting in a thicker product. The observed decrease in the viscosity of sorghum juice following the UF process can be attributed to the retention of solute components on the surface of membrane pores. These pores possess permeability and selectivity, enabling them to effectively separate various molecules, including proteins, fats, and colloidal compounds.

The results indicated that the UF treatment had a significant impact on the overall sugar level of sorghum juice (*Sig* < 0.05). Table 2 illustrates a decline in the total sugar concentration following UF. This observation aligns with the findings of Sasaki et al. (2017) who observed a drop in sucrose concentration following the UF process. This phenomenon can be attributed to the flow and rejection rates of the membrane. As the membrane flow value increases, the rejection coefficient value decreases due to a reduction in the retained sucrose content, and conversely.

The pH value of sorghum juice was not altered by UF treatment (*Sig* > 0.05); however, it did have an impact on the total acidity of the juice (Table 2). The UF treatment shows a tendency to elevate the overall acidity levels. According to Mirwan et al. (2017), the observed phenomenon can be attributed to the retention of various organic components, mineral acids, bacteria, acidic compounds, and other impurities on the surface of the membrane. These contaminants contribute to the acidity of water and subsequently result in an elevation of the pH of the permeate. While the overall acidity rises, the pH value remains rather stable.

The acidity level of the juice serves as an indicator of its quality. Bilal et al. (2017) reported that the pH value of raw juice from the mill station is typically between 5.4 and 5.8, while the temperature is around 27–35°C. This setting provides a favorable environment for the multiplication and growth of bacteria capable of decomposing sucrose into organic acids. Typically, sucrose present in juice could endure in a pH environment exceeding 7.0, indicating an alkaline nature. Hence, in the absence of prompt neutralization of the juice in its acidic condition, it will undergo inversion, resulting in direct injury.

If the juice fermentation process is allowed to continue indefinitely, it might lead to the growth of additional bacteria and the production of organic acids, such as acetic acid. Lime milk is commonly employed in the juice purification process within sugar-based businesses. The addition of lime milk has the potential to alter the acidic nature of juice, resulting in a more alkaline environment (Eggleston & Triplett, 2017). Nevertheless, lime milk was incorporated into the study after the UF procedure.

3.2 Effect of UF and Non-UF on sorghum sugar granules' characteristics

According to the data presented in Table 3, it can be observed that sorghum sugar granules treated with UF exhibits the maximum yield of 4.28%, while the non-UF treated granules provide a yield of 2.38%. The production of crust, which is considered a lost product, is triggered by the greater dissolved solid content in non-UF sorghum sugar granules. Sudarmaji and Saroso (2021) explained that the development of a solid layer on the evaporator's surface is a result of the solution's inclination to settle due to saturation and cling to the surface in a state of supersaturation. The concept of supersaturation refers to a condition wherein a solution exhibits a concentration of dissolved solids that exceeds the equilibrium concentration. In a late-saturated condition, a solution contains many molecules with a lower ionic charge, which tend to aggregate and create a crust.

Table 3 demonstrates that the wettability of sorghum sugar granules remained unaffected by UF treatment. Protein denaturation can lead to a decrease in solubility due to low wettability (Fang et al., 2008; Yüksel, 2021). The solubility of sorghum

Table 2. Effect of the ultrafiltration membrane on the physicochemical properties of sorghum juice.

Characteristics	Sig.	Treatments			
		Non-UF	1x UF	2x UF	3x UF
Total dissolved solids (% Brix)	0.003	13.90 ± 0.14 ^{c}	12.00 ^{a}	13.00 ^{b}	13.25 ± 0.35 ^{b}
Color index					
L*	0.000	41.87 ± 0.01 ^{b}	39.70 ± 0.01 ^{a}	39.556 ± 0.01 ^{a}	39.68 ± 0.01 ^{a}
a*	0.000	-3.31± 0.01 ^{a}	-0.41 ± 0.03 ^{b}	-0.34 ± 0.01 ^{c}	-0.03 ± 0.01 ^{d}
b*	0.000	6.81 ± 0.03 ^{b}	3.35 ± 0.01 ^{a}	3.85 ± 0.02 ^{a}	4.10 ± 0.01 ^{a}
Turbidity (A)	0.000	4.73 ± 0.002 ^{b}	0.57 ± 0.002 ^{a}	0.61 ± 0.001 ^{a}	0.57 ^{a}
Viscosity (cp)	0.000	3.51 ± 0.04 ^{b}	3.33 ± 0.04 ^{b}	3.33 ± 0.13 ^{b}	2.16 ± 0.09 ^{a}
pH	1.000	5.30 ^{a}	5.30 ^{a}	5.30 ^{a}	5.30 ± 0.14 ^{a}
Total sugar (%)	0.001	34.11 ± 3.74 ^{c}	23.67 ± 0.55 ^{b}	12.78 ± 1.22 ^{a}	9.10 ± 1.48 ^{a}
Total acid (mEq NaOH/g)	0.020	0.010 ± 0.002 ^{a}	0.021 ± 0.002 ^{b}	0.022 ± 0.002 ^{bc}	0.031 ± 0.006 ^{c}

Remarks: Sig. < 0.05 indicates the treatment affects the parameters; *Sig.* > 0.05 indicates the treatment does not affect the parameters. Numbers followed by the same letter on one line show no real difference at the level of 5%.

sugar granules was modified by UF treatment. The solubility of sorghum sugar granules treated with UF was lower compared to those treated without UF. Therefore, it can be inferred that sorghum sugar granules treated with UF dissolve more rapidly in water than those treated without UF. According to Yüksel (2021), the findings on wettability demonstrate a strong correlation between the solubility and wettability measurements.

The bulk density and tap density of sorghum sugar granules were likewise affected by the UF treatment. The bulk density observed in the absence of UF treatment was found to be lower compared to the UF treatment. Consequently, it can be inferred that UF sugar granules necessitate smaller containers for an equivalent mass of sugar. Both treatments have a tap density that is nearly equivalent to the bulk density. Hamsinah and Ririn (2020) claimed that a proximity between bulk density and compressible density values suggests a reduced occurrence of particle interactions. The proximity of these values can be determined by examining the compressibility index, also known as Carr's index. If there is a substantial interaction among particles, it will have an impact on the rate at which granules flow, thus influencing the filling of granules within the container.

According to Hamsinah and Ririn (2020), the compressibility index, alternatively referred to as Carr's index, is utilized to assess the tactile properties of a powder. The level of contact is typically less pronounced in the case of free-flowing powders, resulting in a proximity between bulk and compressible density values. Materials exhibiting inadequate flow characteristics frequently exhibit enhanced particle interactions, resulting in notable disparities between bulk density and compressed density.

Table 3. Effect of the ultrafiltration membrane on the physicochemical properties of sorghum sugar granules.

Parameter	Sig. 5%	Treatment	
		Non-UF	UF
Yield (%)	0.005	2.38 ± 0.20	4.28 ± 0.22
Wettability (s)	0.087	0.57 ± 0.14	0.24 ± 0.05
Solubility (s)	0.020	1.38 ± 0.02	1.14 ± 0.04
Bulk density (g/cm^3)	0.001	0.45 ± 0.001	0.57 ± 0.01
Tap density (g/cm^3)	0.002	0.46 ± 0.01	0.62 ± 0.01
Flowability			
Carr index	0.068	0.013 ± 0.01	0.07 ± 0.02
Hausner ratio	0.069	1.01 ± 0.01	1.08 ± 0.02
Color index			
L*	0.003	73.20 ± 0.18	75.46 ± 0.06
a*	0.001	9.41 ± 0.06	6.53 ± 0.07
b*	0.000	23.13 ± 0.50	25.98 ± 0.50
Water content (%)	0.009	2.70 ± 0.21	4.25
Ash content (%)	0.757	0.95 ± 0.03	0.94 ± 0.02
Total sugar (%)	0.001	74.30 ± 0.03	70.62 ± 0.83
Protein (%)	0.388	1.24 ± 0.02	1.22 ± 0.02
Fat (%)	0.360	0.396 ± 0.003	0.398 ± 0.001
Calories (kcal/100 g)	0.000	305.64 ± 0.02	288.40 ± 0.54

Remarks: *Sig.* < α 0.05 indicates that the treatment affects the parameters; *Sig.* > α 0.05 indicates that the treatment does not affect the parameters.

Table 3 shows that the use of UF treatment did not have a significant impact on the Carr Index of sorghum sugar granules. According to Hamsinah and Ririn (2020), the Hausner ratio (HR) serves as an indirect measure of the level of comfort associated with powder flow. The findings of the study also indicated that the application of UF did not have any impact on the HR of sorghum sugar granules. According to Yüksel (2021), a lower HR value suggests better flow qualities compared to higher values. A number between 1.25 and 1.5 indicates intermediate flow properties, while a value above 1.5 indicates poor flow. The confidence intervals for non-UF and UF were 0.013 ± 0.01 and 0.07 ± 0.02, respectively. The HR values were 1.01 ± 0.01 and 1.08 ± 0.02, respectively.

The color values for UF and non-UF sorghum sugar granules are presented in Table 3. The L* value of UF sorghum sugar granules is greater at 75.46 ± 0.06, in comparison to the L* value of non-UF sorghum sugar granules, which is 73.20 ± 0.18. The findings of this study indicate that the use of UF treatment to sorghum juice leads to a considerable improvement in the brightness (L*) of the sugar granules ($p < 0.05$). According to Yüksel (2021), a greater L* value signifies a more intense product, which can be attributed to several aspects such as processing techniques and product composition.

The application of UF treatment results in a notable decrease in the a* color value and a large increase in the b* color value. The observed changes in L*, a*, and b* hues can be attributed to the utilization of UF membranes in the processing of sorghum juice. The pore size of the membrane decreases color by eliminating contaminants, resulting in a purer sorghum juice (Susanto et al., 2013). Furthermore, according to Erwinda and Susanto (2014), the interaction between aldose or ketose groups and amine groups results in the formation of black polymer substances that alter the hue of sugar. UF membranes provide selective permeability, thereby efficiently eliminating contaminants that have an influence on color, thereby yielding a more vibrant sugar product. According to Putra (2016), the presence of protein and reducing sugars in the juice have been suggested to initiate the Maillard reaction, hence potentially influencing alterations in color that may occur over the storage period.

Table 3 demonstrates that the moisture content of sorghum sugar granules was influenced by UF treatment. The water content of non-UF sorghum sugar granules met the requirements described in SNI 01-3743-1995, reaching a level below 3%. However, the UF sorghum sugar fails to meet these parameters as it surpasses the maximum limit specified in SNI 01-3743-1995. Nevertheless, the obtained outcome is comparatively lower than the water content of coconut sugar documented by Naufalin et al. (2017), which ranges from 7.50 to 8.03%. The quality of ant sugar is influenced by its moisture content. A lower moisture level in sorghum sugar granules is indicative of superior quality due to its extended shelf life when stored. The water content of sugar has a significant impact on its hardness. An increase in water content leads to a decrease in sugar hardness, while a decrease in water content results in an increase in hardness (Erwinda & Susanto, 2014).

The data presented in Table 3 indicates that the UF treatment did not have any significant impact on the ash content of sorghum sugar granules. There was no significant difference observed in the ash content generated by the treatments with 0.95% ± 0.03 and 0.94% ± 0.02. The value satisfies the criteria established by SNI 01-3743-1995, which stipulates a maximum limit of 2%.

The application of UF treatment has a notable impact on the overall sugar content of sorghum sugar granules. The non-UF and UF processes yielded a total sugar content of 74.30% ± 0.03 and 70.62% ± 0.83, respectively. Nevertheless, the number failed to meet the criteria established by SNI-SII 0268-85, as defined by Haryanti and Mustaufik (2011), which stipulates a minimum threshold of 80%. It is justifiable to examine the raw materials employed as sorghum sugar granules is derived from sorghum juice, which differs from the raw materials specified in the SNI (Indonesian National Standard), specifically the coconut/palm group. UF sorghum sugar granules have a reduced total sugar concentration compared to non-UF sugar. According to Fauzia et al. (2018), the reduction in sugar content in sorghum juice is attributed to the process of UF applied to the raw material. The cause of this phenomenon can be attributed to the flow and rejection rates of the membrane. As the membrane flow value increases, the rejection coefficient value decreases due to a reduction in the retained sucrose content, and conversely.

The application of UF did not yield any significant changes in the protein and fat composition (Table 3). The protein content was measured at 1.24% (non-UF) and 1.22% (UF), while the fat level was found to be 0.396% (non-UF) and 0.398% (UF). According to the Export News of the Ministry of Trade (2017), the specified protein level in the product falls within the range of 1–2%, while the fat content ranges from 0.5 to 1%. The protein identified in sugar crystals is believed to originate from sorghum juice, which is the primary source in its simple state. The presence of protein in sorghum sugar granule products is also responsible for the development of a brown hue.

The energy calculations yielded values of 305.64 and 288.40 kcal/100 g for non-UF and UF, respectively. The disparity arises due to the elevated overall sugar level seen in non-UF sorghum sugar granules, which consequently leads to a greater energy contribution from fat in comparison to UF sorghum sugar granules. According to Assah (2020), the calorie content of granulated sugar/sucrose utilized as a sweetening agent is 3.94 kcal/g, equivalent to 394 kcal/100 g. Furthermore, according to Assah (2020), palm granule sugar products exhibit the maximum calorific value in the pH 7.7 treatment, measuring 3,600 cal/gg (360 kcal/100 g), while the lowest calorific value is observed in the pH 5.3 treatment, measuring 3467 cal/g (346.7 kcal/100 g). Typically, the calorie content of sorghum sugar granules is comparatively lower when compared to palm granular sugar.

3.3 Consumer preferences for sorghum sugar granules

3.3.1 Granular formed preferences

Figure 3 presents the average sensory score of sorghum sugar granules. UF treatment did not affect the color preference of sorghum sugar granules. Non-UF sugar has an average score of 5.37, while UF sugar was 5.03. Consumers have a slight preference for both colors. Non-UF sorghum sugar granules were brown, while UF sorghum sugar granules were creamy white (slightly brown). The UF treatment has dramatically reduced the substances that affect the brown color, resulting in sugar brighter.

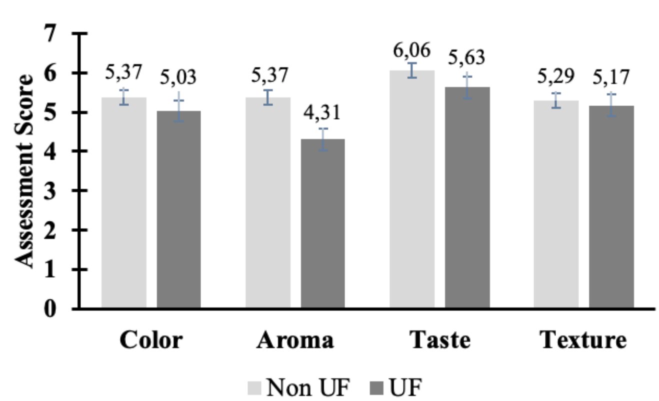
UF treatment affected the granules' aroma preference. Non-UF sugar had an average score of 5.37, while UF sugar was 4.31. It can be concluded that on the aroma attribute, non-UF sorghum sugar granules are preferred over UF sorghum sugar granules. The aroma of sorghum sugar granule products is affected by the characteristics of the raw material, namely sorghum juice, which contains various types of sugars and amino acids. According to Erwinda and Susanto (2014), aldose or ketose groups will react in different ways with amine groups if they are heated in a solution. These reactions will create different compounds, such as flavor and aroma compounds.

Regarding taste, it was found that UF did not affect the taste preference. On the taste attribute, both are liked by consumers. The characteristics of its raw materials influence the taste of a product. UF treatment also did not affect the texture preference. Consumers prefer both. The texture of UF sorghum sugar granules was smoother and felt moister because the moisture content was slightly higher.

3.3.2 Application as a tea sweetener

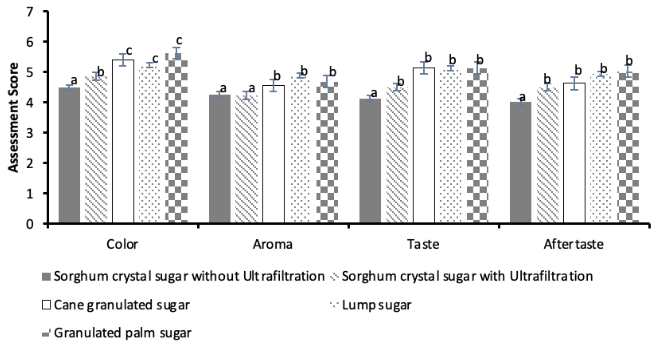
Hedonic experiments were done by panelists to assess the consumer preference for steeping black tea with different sweeteners. These tests included flavor, color, aroma, taste, and aftertaste. Figure 4 illustrates the mean score of customer preference for steeping black tea with different sweeteners, focusing on the aspects of color, aroma, taste, and aftertaste.

Studies have shown that the selection of sweeteners has an impact on the desired hue of tea. The sweetener neutrality of black tea was perceived by consumers when steeped with non-UF sorghum sugar granules; however, consumers exhibited a slight preference for UF sorghum. Consumers show a preference for consuming black tea infused with sweeteners such as granulated sugar, lump sugar, and palm granular sugar.



Score: 1: very dislike to 7: very like

Figure 3. Consumer preference for sorghum sugar granules.



Different letters show a noticeable difference at the level of 5 %. Score: 1: very dislike to 7: very like.

Figure 4. Consumer preference scores for steeping black tea with various sweeteners.

Tea exhibited a darker appearance when non-UF sorghum sugar and palm sugar were used. This can be attributed to the brown hue exhibited by the sweetener. The hue of tea sweetened with UF sorghum sugar, granulated sugar, and lump sugar exhibited minimal alteration due to the colorless nature of the sweetener upon dissolution.

The aroma choice of tea was also influenced by the change of sweeteners. Consumers expressed a preference for steeping black tea with non-UF sorghum sugar and UF sorghum sugar neutral (ordinary). However, they showed a little preference for steeping black tea with granulated sugar, lump sugar, palm sugar, and sugar.

The flavor profile was influenced by the specific sweetener employed. The taste perception of consumers was shown to be neutral when steeping black tea with non-UF sorghum sugar granules; however, they exhibited a little preference for steeping black tea with UF sorghum sugar granules, granulated sugar, lump sugar, and palm sugar. According to Stone et al. (2008), the panelists' approval of taste was influenced by chemical compounds, temperature, concentration, and interactions with other flavor components in the product.

The aftertaste was modified by the specific sweetener used. Tea containing non-UF sorghum sugar granules was perceived by consumers as neutral or usual. On the other hand, customers exhibited a moderate preference for tea including UF sorghum sugar granules, sweetener, granulated sugar, lump sugar, and palm sugar. Tannins present in black tea contribute to the astringent flavor found in processed goods, while caffeine imparts a naturally bitter taste. According to Kurniawati (2017), the presence of a bitter aftertaste on the tongue can influence the evaluation of the sweetness level of the sample while attempting to taste it.

4 CONCLUSION

Sorghum sugar granules' physicochemical properties and consumer preferences were noticeably altered after UF was applied to sorghum juice. Sorghum juice underwent UF treatment improved its clarity, brightness, and overall taste while reducing sugar, turbidity, and total dissolved solids. The treatment also affected the sugar granules' color properties; they turned out brighter (a positive b* value) and less green (a lower a* value), leaning more toward a yellowish hue. In addition, the sugar granules' total sugar content, water content, and energy content were all impacted by the UF treatment. Granules made from UF-treated sugar had less total sugar and more water than non-UF sugar, leading to less energy. There was also a change to the texture, bulk density, and tap density of the sugar granules; UF-treated sugar had a denser bulk and a more uniform tap density. In general, consumers showed the greatest preference for steeping black tea sweetened with palm sugar, followed by lump sugar, granulated sugar, UF sorghum sugar granules, and non-UF sorghum sugar granules.

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