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Influence of conventional and organic farming systems on brown sugar quality

Influência dos sistemas de cultivo convencional e orgânico na qualidade de açúcares mascavo

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Highlights

The brown sugar samples analyzed presented adequate health and hygiene quality.
The type of cultivation did not interfere with the sugar's sensory acceptability.
There is no nutritional advantage of organic brown sugar over conventional one.
The mineral content is independent of the system of cultivation.

Abstract

Brown sugar is obtained from sugarcane juice, preserving its properties almost unchanged from the raw material. Sugarcane cultivation may be carried out using either a conventional or organic production system, where the latter stands out for its growing demand linked to nutritional quality, food safety, and environmental issues appeal. This study aimed to analyze the influences of organic and conventional production systems on the physical-chemical, sensory properties, and sanitary-hygienic quality of commercial brown sugar. Eleven samples (05 conventional and 06 organic) were analyzed. The results were treated statistically using analysis of variance and submitted to the Tukey Test when a significant difference was detected at the 5% level. The samples, regardless of the type of cultivation, showed varied results for the attributes moisture (0.80 to 3.24%), pH (6.03 to 8.71), ash (0.35 to 2.36%), conductimetric ash (0.88 to 6.35%), glucose-reducing carbohydrates (3.09 to 7.91%), and polarity (80.19 to 92.95 °Z). For the attribute polarity, only five samples met the only parameter set by law (above 90.0 °Z). The color showed luminosity between 44.05 and 61.72. As for minerals and metals, sample OBS3 showed the highest Ca

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(1,829.27 mg kg^{-1}) and Mg (885.31 mg kg^{-1}) concentrations. Sample OBS1 showed greater amounts of Mn (18.26 mg kg^{-1}) and had the lowest concentration of Al (1.02 mg kg^{-1}). Sample OBS4 had the lowest content of Na (7.27 mg kg^{-1}); sample OBS6 had the lowest Cu content (3.06 mg kg^{-1}) and the highest Zn content (6.43 mg kg^{-1}). The highest Fe concentration was present in the CBS4 sample, with 137.47 mg kg^{-1}. The heavy metal Pb was not detected in samples CBS2, CBS3, and OBS3. The samples presented satisfactory results and indicative of hygienic-sanitary practices by microscopic and microbiological analysis, with the absence of Coliforms at 45 ºC and *Salmonella* sp. and acceptable mesophile, mold, and yeast values. Sensory analysis showed no statistically significant difference ($p > 0.05$) among the evaluated attributes: color, visual granularity, sweet taste, characteristic aroma, solubility in the mouth, and overall acceptance. Regarding the type of sugarcane cultivation, the results could not confirm any advantage in the nutritional quality and sanitary hygiene of either conventional or organic brown sugar.

Key words: Brown sugar. Food security. Nutritional quality. Productive systems.

Resumo

O açúcar mascavo é obtido a partir do caldo de cana-de-açúcar conservando suas propriedades quase inalteradas quando comparado à matéria-prima. O cultivo da cana-de-açúcar pode ser realizado por sistema de agricultura convencional ou por sistema de produção orgânica, o qual se destaca por sua crescente demanda ligada ao apelo à qualidade nutricional, segurança dos alimentos e questões ambientais. Este trabalho teve por objetivo analisar as influências dos sistemas de produção orgânico e convencional nas propriedades físico-químicas, sensoriais e na qualidade higiênico sanitária de açúcares mascavo comerciais. Para tal, onze amostras (05 convencionais e 06 orgânicas) foram analisadas. Os resultados foram tratados estatisticamente empregando análise de variância e, quando detectado diferença significativa ao nível de 5%, foram submetidos ao Teste de Tukey. As amostras, independente do tipo de cultivo, apresentaram resultados variáveis para os atributos umidade (0,80 a 3,24%), pH (6,03 a 8,71), cinzas (0,35 a 2,36%), cinzas condutimétricas (0,88 a 6,35%), glicídios redutores em glicose (3,09 a 7,91%), polaridade (80,19 a 92,95 °Z), sendo que para este atributo apenas cinco amostras encontraram-se de acordo com o único parâmetro exigido pela legislação (acima de 90,0 °Z); a cor apresentou luminosidade entre 44,05 a 61,72. Quanto aos minerais e metais, a amostra MO3 foi responsável pelas maiores concentrações de Ca (1.829,27 mg kg^{-1}) e Mg (885,31 mg kg^{-1}); na amostra MO1 o Mn esteve presente em maior quantidade (18,26 mg kg^{-1}) e apresentou a menor concentração do elemento Al (1,02 mg kg^{-1}); a MO4 obteve menor teor para o mineral Na (7,27 mg kg^{-1}); a MO6 apresentou o teor mais baixo para o metal pesado Cu (3,06 mg kg^{-1}) e mais elevado para o Zn com 6,43 mg kg^{-1}; a concentração mais elevada de Fe esteve presente na amostra MC4, com 137,47 mg kg^{-1}; o metal pesado Pb apenas não foi detectado nas amostras MC2, MC3 e MO3. As amostras apresentaram resultados satisfatórios e indicativos de práticas higiênico-sanitárias pela análise microscópica e microbiológica, com ausência de Coliformes a 45 ºC e Salmonella sp. e valores aceitáveis de mesófilos, bolores e leveduras. A análise sensorial não apresentou diferença estatística significativa ($p > 0,05$) entre os atributos avaliados: cor, granulosidade visual, sabor doce, aroma característico, solubilidade na boca e aceitação global. Em relação ao tipo de cultivo da cana-de-açúcar, os resultados em geral não permitiram afirmar a existência de vantagem na qualidade nutricional e higiênico sanitária do açúcar mascavo convencional ou orgânico.

Palavras-chave: Açúcar mascavo. Segurança dos alimentos. Qualidade nutricional. Sistemas produtivos.

Introduction

Sugarcane (*Saccharum* spp), the raw material for obtaining brown sugar, was one of the first crops introduced in Brazil and has adapted very well to local climatic conditions, grown in tropical or subtropical areas of the world. Brazil is currently the world's largest producer of sugarcane. The production estimate for the 2021/2022 harvest forecasts 568.4 million tons of sugarcane, and sugar production is estimated at 33.9 million tons, where the state of Paraná is among the top three national producers of the product (Companhia Nacional de Abastecimento [CONAB], 2021; Eggleston, 2018).

Among the types of sugars is brown sugar, in which the production steps consist of extracting the sugarcane juice by a milling process, evaporating the water, concentrating this juice until a thick syrup or molasses is obtained, followed by crystallization by vigorous mechanical agitation at temperatures between 115 and 120 °C, and cooling (Velásquez et al., 2019; Vera-Gutiérrez et al., 2019). Its brown color is due to not undergoing the typical chemical refinement process, such as juice clarification, where precipitating agents such as SO2 and milk of lime are added, eliminating impurities and consequently dragging the main nutrients found in the juice (Gta Alimentos, 2018; Lee et al., 2018; Machado, 2012).

The Brazilian Health Regulatory Agency (ANVISA) with its Resolution (RDC) nº 271 from 22 Sep 2005 defines sugar as either "the sucrose obtained from the juice of sugar cane (*Saccharum officinarum* L.) or beet juice (*Beta alba* L.)" (Resolução nº 271, 2005). It revoked CNNPA RDC nº 12 of 1978, the only one that until then cited and classified brown sugar as containing at least 90% sucrose, free of fermentation, earthy matter, parasites, and animal or plant debris, with an appearance, color, and smell characteristic of the type of sugar used in the manufacturing process, and a sweet taste (Resolução nº 12, 1978). The most recent standard in force is the Ministry of Agriculture's (MAPA) Normative Instruction nº 47, dated August 30, 2018, which defines the classification, identity, and quality requirements for sugars; however, it does not mention brown sugar. It maintained the standards established in past standards, such as RDC nº 271/05, stating that the product may also be designated by the name consecrated by use, which may be followed by expressions relating to the process of obtaining and/or form of presentation and/or purpose of use and/or specific characteristics (Resolução nº 47, 2018; Resolução nº 271, 2005).

Sugarcane cultivation may take place via the conventional agriculture system, characterized by intensive use of synthetic chemical inputs, machinery, mechanical equipment, and improved seeds, or by organic agriculture, whose system is based on production standards aimed at obtaining socially, ecologically and economically sustainable ecosystems, with specific production requirements (Codex Alimentarius Commission, 2016). The Brazilian Law nº 10,831 of December 23, 2003, which provides for organic agriculture and other provisions, vetoes synthetic materials, genetically modified organisms, and ionizing radiation (Lei nº 10.831, 2003).

The demand for organic foods is partly driven by consumers' perception that they are more nutritious. Brown sugar has been used as a natural sweetener replacing refined white sugar as it is a potentially bioactive product, mainly for its antioxidant activity caused by the significant retention of phenolic compounds and flavonoids from the sugarcane juice, increasing its nutritional quality (Lee et al., 2018; Velásquez et al., 2019). These two factors combined potentiate the consumption of the product, making it more attractive and distinctive in the market. However, scientific opinion is divided on whether there are significant nutritional differences between organic and non-organic foods (Barański et al., 2014). The comparative studies on this subject are contradictory and do not allow to affirm any significant difference (Gomiero, 2018; Sousa et al., 2012). Thus, this study aimed to analyze the influence of organic and conventional production systems on the final composition of commercial brown sugars, by physical-chemical, hygienic-sanitary, and sensory analysis of the product, given the lack of legislation standardizing its processing.

Materials and Methods

Collection, transportation, and storage of samples

After surveying the local trade, 11 brands of brown sugar (6 organic and 5 conventional) were selected. The number of packages collected per lot was determined according to the analytical standards of the Instituto Adolfo Lutz [IAL] (2008), in their original packaging, transported and stored at room temperature and protected from humidity until the analysis.

Chemical composition and physical-chemical properties determination

The samples were submitted to humidity analysis using the loss of mass method by oven drying at 105 °C (117/IV); pH by potentiometry (017/IV); ashes by incineration in a muffle furnace at 550 °C (018/IV); reducing glycides in glucose (% w/w), by Fehling's method (038/IV), both recommended in Physical-Chemical Methods for Food Analysis of IAL (2008); polarity and conductimetric ashes as per methods of the International Commission for Uniform Methods of Sugar Analysis ([ICUMSA] 2011, 1994); and color by determining L* parameters for luminosity, and the a* and b* chromaticity coordinates, using a colorimeter (Konica Minolta Sensing, INC, Chroma Meter CR-400, Japan) (Durán et al., 2012). All analyses were done in triplicate.

Metal determination

For this study, analytical-grade reagents were used. Nitric acid (HNO_3) (purity ≥ 65%, Sigma Aldrich, St. Louis, USA) was previously purified in a quartz sub-bubbling system (model DuoPur®, Milestone, Sorisole, Italy). A 10% (w/w) HNO_3 cleaning solution decontaminated all materials. For ICP-OES calibration, aqueous reference solutions were prepared from an SCP33MS multi-elemental standard (10 mg L^{-1}, PlasmaCal ICP-OES & ICP-MS®, SCP Science, Baie-d'Urfé, Canada). The analysis procedure's accuracy was verified using a standard reference material (Embrapa RM-Agro E1001 (FO-01/12), *Brachiaria brizantha Marandu*) digested under the same conditions applied for the sugar samples. The purified water used to prepare reference solutions and dilutions was obtained with an ultra-purifying system (18.2 MΩ cm resistivity, Master System®, Gehaka, São Paulo, Brazil).

Preliminarily for the Al, Ca, Fe, Mg, Mn, Na, Pb, Zn, and Cu analysis, the samples were opened by wet digestion in a microwave oven (Multiwave GO®, Anton Paar, Graz, Austria) using the USEPA 3052 protocol. Sugar samples (0.4 g) were weighed into 50 mL PTFE-TFM flasks (withstanding 310 °C and 40 bar), added 3 mL HNO_3 (65% w/w) and 2 mL H_2O_2 (30% w/w). The reaction proceeded at room temperature with the flask open for 20 minutes. The PTFE-TFM flasks were closed and microwave-oven-heated at 180 °C for 10 minutes. After cooling for approximately 45 minutes, the digests were transferred to 50 mL vials and volumized with deionized water. Afterward, the elements were determined by ICP-OES (Spectro, model Ciros CCD®, Australia) equipped with a pneumatic nebulizer using argon gas (> 99.998%, White Martins, São Paulo, Brazil) to generate the plasma, with a nebulizer and auxiliary gas.

Microscopic analysis

The samples were submitted to the detection of light dirt and foreign matter by the flotation method in a Wildman trap flask as recommended by the Technical Standard for Microscopic Methods of Food Analysis (IAL, 1999). After that, the samples were visualized in an optical electron microscope (CX21FS1, Olympus, Tokyo, Japan).

Microbiological analysis

The samples were evaluated for counting of *Coliforms* at 45 ºC g^{-1} (mL) and *Salmonella* sp. at 25 ºC g^{-1} (Resolução nº 12, 2001), as well as viable strict and facultative aerobic mesophiles and molds and yeasts, according to the official methods for microbiological analysis recommended by Normative Instruction nº 62 of August 26, 2003 (Instrução Normativa nº 62, 2003). All samples were evaluated in duplicate.

Sensory analysis

The project was submitted to the ethics committee and approved (CAAE: 08937119.9.0000.5547) following the above microbiological standards. For the sensory analysis, an incomplete block experimental design was used, where all 11 treatments (t = 11) were evaluated in individual booths, lit with white fluorescent light, and divided into 55 blocks (b = 55). Each treatment was evaluated by 10 tasters (r = 10) (M. A. A. Silva & Damasio, 1994). Each taster received 02 different treatments at a time accommodated in disposable plastic cups with about 20 g sample at room temperature, coded adequately with random three-digit numbers (Dutkosky, 2013). 55 analyses were performed. At the same time, an evaluation form was provided, with a 09-point Structured Hedonic Scale, and the attributes color, visual graininess, sweet taste, characteristic aroma, solubility in the mouth, and overall acceptance were evaluated. Before initiating the analysis, the tasters received an Informed Consent Form (ICF) with all relevant information about their participation in the research.

Statistical analysis

The results obtained for each analysis were submitted to ANOVA variance analysis. The Tukey test was performed using the *Statistica* 10.0 software when significant differences were detected at a 5% probability level.

Results and Discussion

Chemical composition and physicochemical properties determination

The current legislation does not set a maximum value for moisture in brown sugar. However, Verruma-Bernardi et al. (2007) suggested values lower than 2.4% due to the product's stability, as it is the most influencing factor in sugar deterioration. Besides contributing to the growth of undesirable microorganisms, such as molds and yeasts, high humidity in brown sugar may cause other problems, such as staling and breakdown of sucrose into glucose and fructose, which implies shorter product shelf life (Verruma-Bernardi et al., 2007). In this study, the organic brown sugar samples' moisture content ranged from 3.24% to 0.80%, in agreement with the study by Bettani et al. (2014), who obtained a 2.90% average moisture value for organic brown sugar. On the other hand, the conventional sugar samples obtained a 3.23% maximum value and a 1.03% minimum (Table 1). Silva et al. (2018), when evaluating 15 brown sugar samples, found similar results that ranged between 0.68 and 4.36%. Jaffé (2015) and Asikin et al. (2015) reported that the relatively large fluctuation in brown sugar moisture is caused by differences in manufacturing process conditions, such as drying-solidification processes mainly in small artisanal processing enterprises.

The pH ranged from 6.03 to 8.31 for conventional brown sugars (CBS) and from 6.22 to 8.71 for organic brown sugars (OBS). The OBS6 and CBS4 samples differed statistically ($p < 0.05$) from the others, presenting a more basic pH (8.71 and 8.31, respectively), according to Table 1, and the samples CBS3 and OBS1 presented a more acidic pH. Andrade et al. (2018) suggested an inversely proportional relation between moisture content and pH and proposed its monitoring during brown sugar processing since the lower the moisture and the higher the pH (above 6, 0), the shorter the time required for its evaporation and consequently the lower the probability of sucrose inversion occurrence (Alarcón et al., 2021), due to low humidity and neutral pH. This results in hygroscopic glucose and fructose-reducing sugars. The results obtained in this study corroborate the results described in the literature, with only samples CBS1 and CBS2 showing smaller differences regarding this inverse relation.

Table 1
Chemical composition and physical-chemical properties of commercial brown sugar of conventional and organic origin

Samples	Moisture % (w.w^{-1})	pH	Ashes % (w.w^{-1})	C. C.^{1} % (w.w^{-1})	R. G. G.^{2} % (w.w^{-1})	Polarity (°Z)
CBS1	2,27 ± 0,02^{b}	6,74 ± 0,04^{e}	2,36 ± 0,00^{a}	6,31 ± 0,26^{a}	4,16 ± 0,09$^{e f g}$	82,80 ± 4,99^{f}
CBS2	2,34 ± 0,06^{b}	6,63 ± 0,03^{e}	1,60 ± 0,04^{d}	6,27 ± 0,13^{a}	5,02 ± 0,07^{d}	84,06 ± 5,23^{e}
CBS3	3,23 ± 0,06^{a}	6,03 ± 0,00^{f}	1,27 ± 0,01^{e}	3,07 ± 0,04^{d}	5,29 ± 0,07^{c}	91,79 ± 3,02^{b}
CBS4	1,03 ± 0,03^{g}	8,31 ± 0,20^{b}	0,64 ± 0,04^{g}	1,52 ± 0,05$^{e f g}$	3,09 ± 0,01^{i}	91,02 ± 2,94^{c}
CBS5	1,39 ± 0,02$^{d e}$	7,63 ± 0,06^{d}	0,84 ± 0,01^{f}	1,80 ± 0,04$^{e f}$	7,91 ± 0,11^{a}	81,64 ± 3,65^{f}
OBS1	3,24 ± 0,10^{a}	6,22 ± 0,03^{f}	1,21 ± 0,04^{e}	3,03 ± 0,18^{d}	3,10 ± 0,07^{i}	92,76 ± 1,45^{a}
OBS2	0,80 ± 0,00^{h}	7,28 ± 0,08^{e}	0,35 ± 0,10^{h}	0,88 ± 0,02^{h}	3,10 ± 0,02^{i}	92,95 ± 2,69^{a}
OBS3	1,75 ± 0,06^{c}	7,18 ± 0,02^{e}	1,79 ± 0,01^{c}	4,25 ± 0,05^{c}	4,01 ± 0,05$^{f g}$	91,31 ± 3,83^{b}
OBS4	1,41 ± 0,06$^{d e}$	7,84 ± 0,01^{c}	0,44 ± 0,01^{h}	1,28 ± 0,02$^{f g}$	7,64 ± 0,05^{b}	80,19 ± 2,21^{g}
OBS5	1,29 ± 0,07$^{d e f}$	7,56 ± 0,01^{d}	2,05 ± 0,01^{b}	5,16 ± 0,03^{b}	4,30 ± 0,09$^{e f}$	85,99 ± 6,54^{e}
OBS6	1,19 ± 0,03$^{e f}$	8,71 ± 0,02^{a}	0,42 ± 0,09^{h}	1,45 ± 0,03$^{f g}$	3,53 ± 0,02^{h}	88,89 ± 3,02^{d}

*Conductimetric Ashes^{1}; Reducing Glycides in Glucose^{2}. Equal letters in the same column indicate do not differ statistically significant differences in the results at 5% significance. *CBS = conventional brown sugar; OBS = organic brown sugar.

Ash determination provides an estimate of the total mineral content in foods (IAL, 2008; A. F. S. Silva, 2017). The values obtained were between 0.64 and 2.36% for conventional sugars and 0.35 to 2.05% for organic sugars. CBS1 sample presented the highest ash content, 2.36% ($p < 0.05$), differing statistically from the others. The lowest concentrations were obtained in samples OBS2, OBS6, and OBS4, with 0.35, 0.42, and 0.44%. With no standard set by legislation, Lee et al. (2018) obtained values ranging from 0.80 to 1.54% in ash content for four unrefined sugar samples. According to Machado (2012), the ash test also verifies the content of impurities in the product's composition, such as soil and sand, usually from sugarcane harvesting. The author did not specify the type of sugar but reported that values above 0.2% may change the product's sensory characteristics, giving a darker color and sandy appearance. Sampaio et al. (2023) observed that the highest ash levels corresponded to the least processed products, including conventional brown sugar averaging 0.27% ash content and organic brown sugar averaging 0.63% ash content, contrasting with the values in this study.

Conductimetric ash provides a measure of soluble ionized salt concentration in samples with conductivities up to 500 μS cm^{-1} (ICUMSA, 1994). In this study, the values ranged from 6.31 to 1.52% for conventional brown sugar and from 5.16 to 0.88% for organic brown sugar, as seen in Table 1. Noteworthy, the conventional samples CBS1 and CBS2 had no significant difference between their results ($p > 0.05$) and showed the highest percentages (6.31 and 6.27%). The organic sample OBS2 had a significant difference compared to the others ($p < 0.05$) and presented the lowest value (0.88%). Bettani et al. (2014) obtained a 1.35% ash value for organic brown sugar. High ash levels may confer a bitter or salty taste to the products due to the high potassium content, hindering the crystallization process. Due to its importance for brown sugar's end quality, it is proposed that ash value not exceed 2.2% in brown sugar (Lopes & Borges, 2004). Only five samples showed values below the proposed one.

The percentages of reducing glycides in glucose (RGG) ranged from 3.09 to 7.91% in the conventional brown sugar samples, with sample CBS5 showing the highest value and the greatest significant difference from the others ($p < 0.05$). At the same time, the organic samples ranged from 3.10 to 7.64%. Samples CBS4, OBS1, and OBS2 showed the lowest values. Lopes and Borges (2004) suggested that RGG values should be less than 2.4%, considered a yielding technological problem in agribusiness, causing financial losses to the producer. Such a report did not agree with the samples analyzed in this study, with the lowest reducing sugar averages obtained for samples CBS4 (3.09%), OBS1 (3.10%), and OBS2 (3.10%). However, they were close to the values cited by Andrade et al. (2018), who further stated that the high content of RGG is responsible for the increased moisture in the sugar due to its hygroscopic characteristic. Regarding the directly proportional relation between moisture content and reducing sugars, according to Table 1, few samples met the reported requirements. This may be linked to the sugarcane not being fully ripe, the binomial time and temperature used in the process, and also the sucrose inversion during the manufacturing process resulting from the pH/moisture ratio, which may alter this characteristic (Lopes & Borges, 2004; Orlandi et al., 2017).

The conventional brown sugar samples presented a polarimetric deviation between 28.67 and 31.78 $[\alpha]^{20}$, corresponding to 81.64 and 91.79 °Z of apparent sucrose. In contrast, the organic brown sugar samples showed values ranging from 27.76 to 32.18 $[\alpha]^{20}$ and 80.19 to 92.95 °Z, respectively. The OBS2 and OBS1 samples were purer in terms of sucrose concentration. The lowest percentage of sucrose was obtained in sample OBS4, differing from the others ($p < 0.05$). All results obtained by Andrade et al. (2018) were lower than the regulation ones (71.1 to 84.5%). The speed of sucrose decomposition reaction by inversion or hydrolysis is inversely proportional to pH and directly proportional to juice temperature. The optical rotation principle is the algebraic sum of the predominant effects of the sample's sucrose content, which is modified by the presence of reducing sugars and other optically active polysaccharides, and the clarification procedure used. Therefore, lower sucrose content indicates a higher presence of reducing sugars (glucose and fructose), dextran, starch, and ash (ICUMSA, 2011; Machado, 2012; Minguetti, 2012), agreeing with the results showed in samples CBS5 and OBS4, which showed the lowest sucrose contents and highest reducing glycide contents. Given this perspective, only five out of the 11 samples met the specific legislation for brown sugar (minimum 90.0% sucrose (or 90 °Z)) (Resolução nº 12, 1978).

For the luminosity (L* axis), sample CBS1 had the highest value (61.72), representing the lightest sample, and sample OBS5 presented the lowest average value of 44.05 and, therefore, the darkest shade, both statistically different from each other and from the other samples ($p < 0.05$), as shown in Table 2. For a* axis, sample OBS3 showed a significant difference ($p < 0.05$), with a 5.50 average, representing a reddish shade more intense than the others, and samples CBS3 and OBS6 with lower intensity did not differ ($p > 0.05$). The b* axis that represents a scale of yellowish tones, the conventional brown sugar CBS1 showed the highest value, statistically different from the others ($p < 0.05$), which may be related to low brightness (L*). Sample OBS6 presented the lowest b* value, making it the most neutral in tone. Both colors are visually compared from left to right in Figure 1. The conventional brown sugar samples CBS1, CBS2, CBS3, CBS4, and CBS5 are at the top, and the organic brown sugar samples OBS1, OBS2, OBS3, OBS4, OBS5, and OBS6 are at the bottom.

Table 2

Mean results of color analysis by the colorimetric method of commercial brown sugar of conventional and organic origin

Samples	Color		
	L*	a*	b*
CBS1	61,72 ± 0,18 ^{a}	3,09 ± 0,25 ^{c}	33,18 ± 0,22 ^{a}
CBS2	54,55 ± 0,12 ^{c}	3,01 ± 0,03 ^{c}	28,84 ± 0,03 $^{d\,c}$
CBS3	49,26 ± 0,37 ^{f}	1,74 ± 0,03 ^{f}	28,26 ± 0,16 ^{d}
CBS4	53,12 ± 0,30 ^{d}	2,16 ± 0,05 ^{e}	24,34 ± 0,07 ^{g}
CBS5	52,67 ± 0,54 $^{d\,e}$	2,61 ± 0,07 ^{d}	24,31 ± 0,30 ^{g}
OBS1	57,91 ± 0,31 ^{b}	3,81 ± 0,03 ^{b}	31,57 ± 0,20 ^{b}
OBS2	57,82 ± 0,34 ^{b}	2,63 ± 0,09 ^{d}	26,40 ± 0,03 ^{e}
OBS3	47,11 ± 0,37 ^{g}	5,50 ± 0,02 ^{a}	29,03 ± 0,25 ^{c}
OBS4	51,30 ± 0,94 ^{e}	2,83 ± 0,12 $^{d\,c}$	25,33 ± 0,25 ^{f}
OBS5	44,05 ± 0,79 ^{h}	3,90 ± 0,04 ^{b}	26,11 ± 0,30 ^{e}
OBS6	52,79 ± 0,45 ^{d}	1,51 ± 0,07 ^{f}	23,10 ± 0,20 ^{h}

* Equal letters in the same column indicate do not differ statistically significant differences in the results at 5% significance. * CBS = conventional brown sugar; OBS = organic brown sugar.

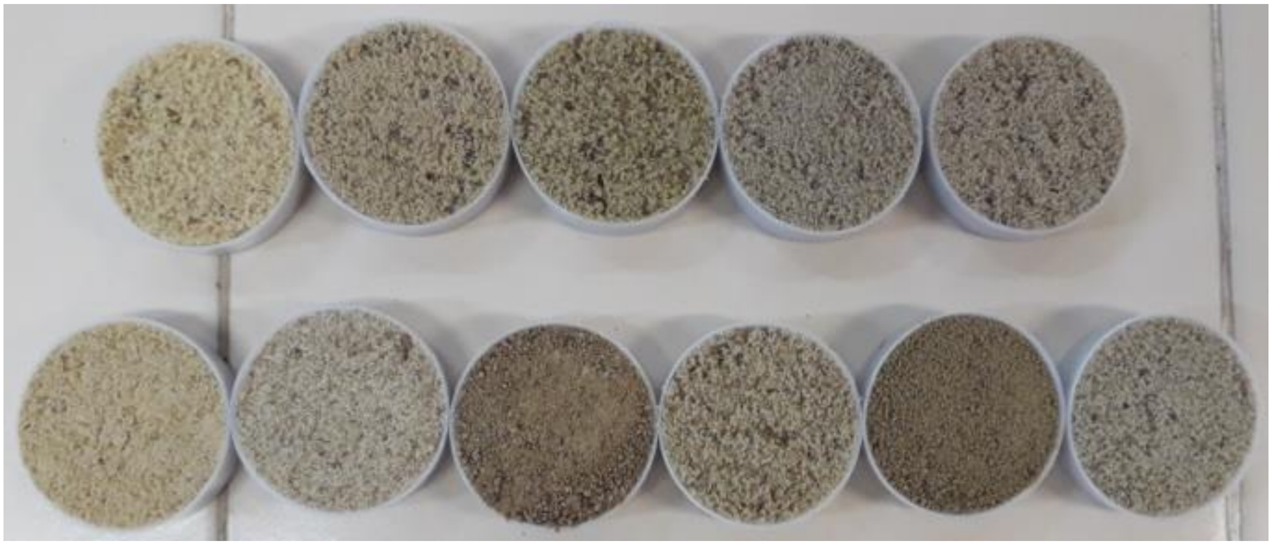

Figure 1. Visible color of commercial brown sugar of conventional and organic origin.

Silva et al. (2018) obtained a range from 45.0 to 67.4 for the luminosity parameter (L* axis) for 15 brown sugar samples, while Lee et al. (2018) obtained values ranging from 38.45 to 56.80 for 4 unrefined sugar samples. According to the above, three of the eleven samples analyzed in this study were opposed, showing higher average values (lighter samples) and one lower (darker). Brown sugar has a darker color because of molasses in its contents, and it may be influenced by the variety of sugar cane and the location where it was grown as they may result in mineral- and phenolic-compound-rich juices. When oxidized by the action of phenoloxidases enzymes (PO), they form quinones, a reaction catalyzed by the presence of metals such as iron (Fe), common in this type of sugar, which participate in addition reactions with other cellular compounds such as proteins and starch, giving dark color to sugars (Alarcón et al., 2021; Lopes & Borges, 2004; Vera-Gutiérrez et al., 2019). During the juice processing, colored materials, such as melanoidins, responsible for the yellow color, and caramels, characterized by more intense coloration, are formed. Changes may also occur during storage time with a tendency to darken as the Maillard reaction progresses (Alarcón et al., 2021; Asikin et al., 2014; García et al., 2017; Lopes & Borges, 2004; Vitao Alimentos [Vitao], 2019).

Minerals and metals determination

Sample OBS2 showed the lowest Ca, Fe, Mg, and Mn concentrations (Figure 2). However, it showed the highest Pb content. The increase in blood concentration of Pb may bring numerous deleterious consequences at different stages of life, such as altered behavior, cognitive performance, postnatal growth, delayed puberty, and reduced hearing ability in infants and children. Pb may cause cardiovascular, central nervous system, kidney, and fertility-related problems in adults; during pregnancy, it may impair fetal growth at the early stage (Kumar et al., 2020). Lee et al. (2018), when evaluating four unrefined sugar samples, obtained similar values for Fe, ranging from 22.44 to 29.32 mg kg^{-1}. Wilwerth et al. (2009), when evaluating 31 different brands of brown sugar, obtained an average range from 6.3 to 16.2 mg kg^{-1} for Pb. Sample OBS3 presented the highest Ca (1829.27 mg kg^{-1}) and Mg (885.31 mg kg^{-1}) concentrations. Similar results for magnesium were reported by Lee et al. (2018), ranging from 485.80 to 815.20 mg kg^{-1}. For Ca, higher values were found by Watanabe et al. (2018) when evaluating eight non-centrifuged cane sugar samples (NCS) collected at different times, obtaining averages ranging from 2050 to 2230 mg kg^{-1}.

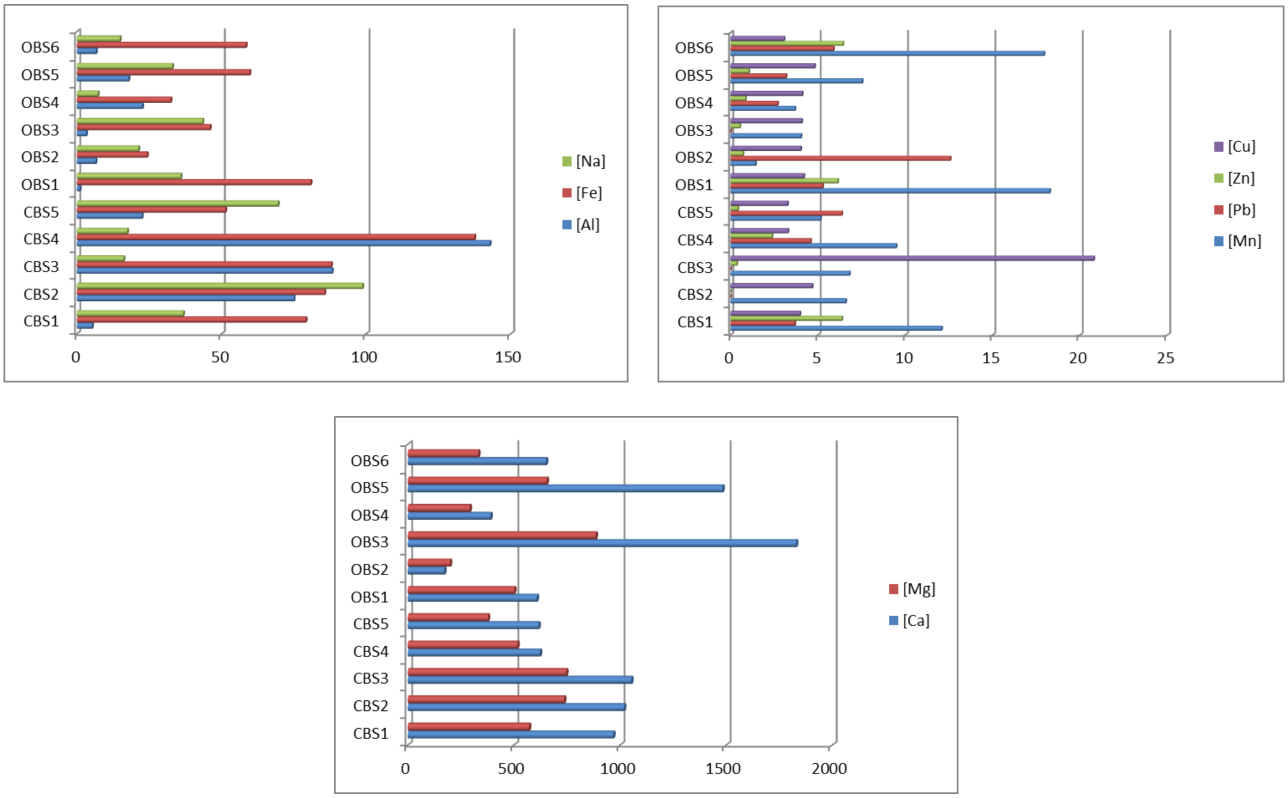

Figure 2. Determination of metals and minerals in commercial brown sugar of conventional and organic origin by ICP-OES. Results expressed in mg kg^{-1} (ppm). *CBS = conventional brown sugar; OBS = organic brown sugar.

Sample CBS3 showed the highest Cu (20.78 mg kg^{-1}) content. Sample CBS2 presented the highest Na content (98.71 mg kg^{-1}), and Zn was undetected. Lower results for Cu, between 14.3 and 12.1 mg kg^{-1}, were reported by Takahashi et al. (2016), evidencing the need to evaluate further this sugar processing method or the type of agricultural system used in the production of the raw material. On the other hand, higher Na values were found by Watanabe et al. (2018), between 410 and 500 mg kg^{-1}, showing the low-sodium-content characteristic of sugars.

Sample OBS1 showed the highest amount of Mn (18.26 mg kg^{-1}) and the lowest Al concentration (1.02 mg kg^{-1}). Sample OBS4 had the lowest Na content (7.27 mg kg^{-1}). Sample OBS6 showed the lowest Cu content (3.06 mg kg^{-1}) and the highest Zn content (6.43 mg kg^{-1}). Similar results were reported by Luchini et al. (2017) when evaluating the influence of organic and conventional fertilization on brown sugars' nutritional quality using the flame atomic absorption spectrometry (FAAS) method, obtained averages ranging from 15.33 to 20.46 mg kg^{-1} for Mn and from 4.90 to 5.99 mg kg^{-1} for Zn.

The highest Al and Fe concentrations were found in sample CBS4, with 142.78 and 137.47 mg kg^{-1}, respectively. Wilwerth et al. (2009) obtained Al concentrations ranging from 17.5 to 453.8 mg kg^{-1} and Fe ranging from 29.9 to 488.4 mg kg^{-1}. Iron is an essential element with critical functions such as oxygen transport, DNA synthesis, and muscle metabolism. Its deficiency is the leading cause of anemia, the most prevalent nutritional deficiency worldwide (World Health Organization [WHO], 2020). It is worth noting that the legislation does not typify sugar, covering sugars in general, which highlights the importance of developing a technical regulation of identity and quality that standardizes the requirements for brown sugar since it is proven that this type of sugar has different characteristics from others due to its processing method preserving the raw material's nutritional aspects, such as Fe, an essential mineral for the human body's proper functioning, where, taking sample CBS4 for instance, 50 g of its consumption would be equivalent to 49% of the recommended Fe daily intake. It states that brown sugar would be an alternative source of Fe when replacing white crystal sugar in the diet (Organização Mundial da Saúde [OMS], 2015).

There is a relatively wide dispersion in element data reported by the literature, which are shown by large standard deviations and reflect the likely influence of agronomic conditions, such as atmospheric deposition, sugarcane variety, soil types, and management, application of correctives, fertilizers and agrochemicals, irrigation water, organic and inorganic residue addition, harvesting and manufacturing process conditions, as well as different analytical methods used for evaluation (Jaffé, 2015; Luchini et al., 2017).

Microscopic analysis

According to the Brazilian Health Regulatory Agency's CNNPA resolution nº 12 of 1978, which classifies sugars - including brown sugar - according to sucrose percentage, the sole current regulation in force presents the absence of dirt, parasites, and larvae as microscopic characteristics (Resolução nº 12, 1978). RDC nº 623 of March 9, 2022, which sets tolerance limits for foreign matter in food, general principles for its consolidation, and methods of analysis for conformity assessment, does not establish specific requirements for brown sugar. Therefore, the general foods group is considered when having to assess it. This group's tolerance limit for acid-insoluble sand or ash is 1.5% (Resolução nº 623, 2022).

As shown in Table 3, all samples are within the established limit; however, presenting other impurities not foreseen by the legislation, and classified as foreign matter, defined as any material that does not constitute the product combined with inadequate production, handling, storage, or distribution practices. It could be exemplified by the colored foreign particle in sample CBS1, the undetected substance and the unidentified fragment in samples CBS4 and OBS2, the brown films found in samples CBS5, OBS1, OBS4, and OBS5, and the wooden stick in sample OBS6. Unavoidable foreign matters occur in the food even when applying best practices, such as the black dots found in six of the 11 samples. Undesirable parts or impurities, which are part of plants or animals affecting the product quality, such as bark, stalks, petioles, cartilage, bones, feathers, and animal hair, and charred particles of food that come from or are not removed by processing, such as sugarcane bagasse found in seven samples, which may also be unavoidable due to the processing characteristics to obtain brown sugar.

Table 3
Light dirt and foreign matter in commercial brown sugar of conventional and organic origin by the Wildman trap flask method

Samples	Light dirt and foreing matter	Units
CBS1	Strange colored particle Black dots	1 3
CBS2	Sugar cane bagasse Black dots	2 5
CBS3	Sugar cane bagasse Black dots	2 7
CBS4	Undetected substance Sugar cane bagasse	1 9
CBS5	Sugar cane bagasse Brown skins	2 3
OBS1	Sugar cane bagasse Brown skins	1 2
OBS2	Undetecded substance Sugar cane bagasse	1 1
OBS3	Sugar cane bagasse Black dots	1 2
OBS4	Brown skins Black dots	5 6
OBS5	Brown skins	4
OBS6	Black dots Kindling	3 1

*CBS = conventional brown sugar; OBS = organic brown sugar.

Silva (2017) characterized insoluble residues in crystal, refined, demerara, and brown sugar samples and reported the main foreign matters: black dots, dark fragments, and material that resemble bagasse. According to RDC nº 47 of August 30, 2018, black dots are particles of contrasting coloration. They may come from caramelized sugar, carbonized sugar, soot, sparks from burning cane, cane fibers, or fouling residues from equipment (Resolução nº 47, 2018). Ramvi (2015), analyzing the brown sugar processing in an agri-foodstuffs company, reported that soon after the cane milling, the juice must pass through decanters to separate the bagasse and larger and denser impurities, such as soil and sand particles. The finest cleaning is done in the pots by removing foam-form impurities, which rise to the surface during the juice boiling. Their removal is done using a skimmer, repeated until the juice is completely clean to ensure a purer and clearer product. These juice-cleaning steps are critical control points for physical hazards in the HACCP system.

Microbiological analysis

The microbiological quality evaluated in the 11 samples of organic and conventional brown sugar is presented in Table 4. Similar results for Coliforms at 45 ºC were found by Araújo et al. (2011). RDC nº 12/01 establishes as a criterion for brown sugar the absence of Salmonella sp in 25 g food samples. All samples follow Brazilian legislation and are suitable for consumption (Resolução nº 12, 2001).

Table 4
Microbiological results of commercial brown sugar of conventional and organic origin

Samples	Coliforms at 45 °C (log CFU g^{-1})	Salmonella sp. (25 g)	Strict and facultative aerobic mesophiles (log CFU g^{-1})	Molds and yeasts (log CFUg^{-1})
CBS1	Absence	Absence	<1,0 ± 0,0	2,2 ± 0,5
CBS2	Absence	Absence	<1,0 ± 0,0	2,5 ± 0,4
CBS3	Absence	Absence	1,0 ± 0,0	2,4 ± 0,4
CBS4	Absence	Absence	1,2 ± 0,2	2,6 ± 0,0
CBS5	Absence	Absence	2,0 ± 0,5	2,5 ± 0,1
OBS1	Absence	Absence	1,1 ± 0,2	2,5 ± 0,4
OBS2	Absence	Absence	<1,0 ± 1,1	2,3 ± 0,3
OBS3	Absence	Absence	1,0 ± 0,0	2,3 ± 0,5
OBS4	Absence	Absence	1,8 ± 0,5	2,2 ± 0,1
OBS5	Absence	Absence	1,9 ± 0,3	2,4 ± 0,1
OBS6	Absence	Absence	<1,0 ± 0,9	2,5 ± 0,0

*CBS = conventional brown sugar; OBS = organic brown sugar.

As for the count of viable strict and facultative aerobic mesophiles, there was a variation in growth from < 1.0 to 2.0 log CFU (Colony forming units) g^{-1} among the samples evaluated. However, Brazilian legislation does not specify a tolerance for this parameter. These results were relatively lower than those of Silva et al. (2018), that, when evaluating 15 samples of brown sugar from different brands, obtained results that varied from <1 to 3.3 x 10^2 CFU/g. Araújo et al. (2011) reported similar values ranging from <1.0 to 1.57 log CFU g^{-1} in 10 brown sugar samples. High values indicate undesirable hygienic-sanitary conditions since mesophilic bacteria in non-perishable foods represent the use of contaminated raw material or unsatisfactory processing from a sanitary viewpoint, reducing the products' shelf life (Jesus, 2010).

As for mold and yeast counts, the current legislation also does not establish maximum permitted tolerance parameters in brown sugars. Within the microbiological analysis applied, this one showed the highest growth, varying from 2.2 to 2.6 log CFU g^{-1}. Compared with the values established by international agencies (Jesus, 2010), all samples analyzed presented values above the required standard and would be unfit for sale. However, such global standards are not applied in Brazil. According to the Cooperativa dos Produtores de Cana, Açúcar e Álcool do Estado de São Paulo [COPERSUCAR] (2018), the maximum standard for the domestic market is 3 log CFU g^{-1}. Therefore, all samples presented in this study were approved according to the domestic market specifications, and the high values found may be related to the humidity of each product, as well as conservation and storage issues. However, given the divergence of values reported, a need for legislation review or the development of specific technical regulations for brown sugar to standardize the microbiological quality standards is perceived.

Sensory analysis

The Hedonic Scale affective test average results concerning each attribute of the 11 organic and conventional brown sugar samples assessed by 55 evaluators, from which 72.7% were female, are reported below. No statistically significant difference was detected among the samples at a 5% probability level for each evaluated attribute.

The color attribute, an essential parameter in appearance perceived in the first consumer-product contact that provides information about the processing, is one of the most critical aspects of acceptance. It is also one of the most complex variables to control (Vera-Gutiérrez et al., 2019). The evaluated conventional brown sugar samples averaged on a scale from 6.1 to 7.8, and the organic samples averaged between 6.3 and 7.4, corresponding to evaluations from "like slightly" to "like moderately". The visual graininess parameter of brown sugar ranged from 6.0 to 7.0 for the conventional samples ("like slightly" to "like moderately") and 5.7 to 8.0 for the organic ones ("neither like nor dislike" to "like very much"). Such difference may be linked to the form of processing, where some steps, such as crumbling and sieving, interfere with the final diameter of the brown sugar granules or particles. Minguetti (2012) reported no significant difference among the samples.

The sweet taste attribute averaged between 6.1 and 7.7 ("like slightly" and "like moderately") for the conventional brown sugar samples and 6.4 to 8.3 ("like slightly" and "like very much") for the organic brown sugar ones. The 11 samples analyzed in this study obtained a good evaluation for this attribute. As seen before, high levels of ash in the product may give it an unpleasant bitter or salty taste, and compounds such as caramel may bring a unique burnt sugar flavor that might or might not please the palate of some consumers.

The brown sugar characteristic aroma values ranged between 6.1 and 7.6, equivalent to "like slightly" and "like moderately" for conventional brown sugar and from 5.7 to 7.9 ("neither like nor dislike" to "like moderately") for organic brown sugar. The aroma makes food pleasant, bringing quality aspects, and is also correlated to the flavor attribute (Minguetti, 2012). Bettani et al. (2014) stated that brown sugar has a stronger aroma when compared to other types of sugar. Minguetti (2012) defined sugar solubility as sugar's ability to come apart in the mouth. The author reported no significant difference among the brown sugar samples produced by different forms of sugarcane cultivation. Bettani et al. (2014) stated that the solubility factor is common among sugars in general, showing good dissolution. There was, therefore, no confrontation between the literature and the values found in this study, which were established from 6.5 to 7.5 for conventional brown sugar samples and from 6.4 to 8.3 for organic brown sugar samples, ranging from "like slightly", "like moderately", and "like very much".

The acceptability index showed that 9 out of 11 samples (82% of the samples) obtained good acceptance (≥ 70%), with samples OBS4 and OBS5 the only less accepted ones, with 67% and 68% acceptability levels, respectively. Sample OBS6 obtained the highest acceptability level with 92% (Table 5). Orlandi et al. (2017) concluded that the choice of sugarcane variety used plays a key role in obtaining a higher quality final product, as the data with the highest overall preference resulted in sugar with a darker appearance, smaller granules, less intense sweet aroma and flavor, and high solubility. Further studies are therefore needed on production systems and their variables.

Table 5
Acceptability index of commercial brown sugar of conventional and organic origin for the overall acceptance attribute

Samples	Overall acceptance	Acceptability Index %
CBS1	7,4	82
CBS2	6,6	73
CBS3	7,5	83
CBS4	6,6	73
CBS5	7,2	80
OBS1	8,2	91
OBS2	7,8	87
OBS3	7,0	78
OBS4	6,0	67
OBS5	6,1	68
OBS6	8,3	92

*CBS = conventional brown sugar; OBS = organic brown sugar.

Conclusions

The results of this study showed that the cultivation type did not significantly impact the physicochemical, sensory, and sanitary quality of commercialized brown sugar samples. The current legislation specifies the polarity parameter (°Z) for brown sugar, where only 45.5% of the samples were compatible with the required percentage. Furthermore, it was verified the difficulty of standardizing the brown sugar production process either through the process variables or the lack of internal regulations, highlighting the urge to update and adapt the current legislation in Brazil.

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