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Effect of different types of sugar on guava jams' physical, physicochemical, and sensory properties

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ABSTRACT. Consumers preference for healthier foods is increasing, especially regarding sugar intake as it is related to many diseases such as obesity and diabetes. This study aimed to evaluate the influence of different types of sugar (white crystal, icing, raw, brown, and coconut) on the physical, physicochemical, and sensory attributes of guava jam in order to evaluate the feasibility of replacing traditional sugars by alternative and more nutritious ones. Physicochemical attributes, rheological properties, texture profile, microbiological risk and sensory acceptance of guava jams were assessed. Coconut and brown sugars gave rise to darker jams with an intense reddish-brown coloration and higher hardness. The jams with higher sensorial quality were the traditional formulations produced with typical sugars - white crystal and icing sugars -, and with raw sugar. It was observed that the sugar used influenced the consumers perception of the product. In general, the most nutritious sugars, brown and coconut, did not produce to jams with good sensory acceptance. White crystal, icing, and raw sugars were more convenient to make the jams since it presented better sensory results. Clear appearance, less sweetness, more acidic, and softer jams are the features that most pleased the consumers.

Keywords: FTIR; rheology; sensory analysis; texture profile analysis.

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Introduction

Consumers health concern, especially regarding their diet, is growing and they are becoming aware that excessive sugar intake can contribute to weight gain and other associated diseases. Thus, the food industry is continually seeking alternatives through the use of different types of sugars that have the potential to be healthier and less offensive to consumers health. However, a sugar-type substitution is associated with significant changes in texture, color, taste, and aroma, and it is, therefore, a significant challenge to find suitable substitutes that may result in satisfactory products (Struck, Jaros, Brennan, & Rohm, 2014).

The main ingredients of traditional jams are white crystal or refined sugars (Curi et al., 2017). Sugar is an essential ingredient in the formulation of various foods, and its chemical structure ensures a sweet taste that makes it ideal to be added to various sweetened products. Crystals of white sugar can be large, transparent, or yellowish crystals. The refinement of sugar stage performed after the extraction of sugarcane causes the mineral salts to be eliminated, generating a product with a lower nutritional value. Some chemical additives are also added - such as clarifiers and preservatives in the extraction and refining steps - which remain in the final product (Curi et al., 2017).

Icing sugar undergoes a bleaching step with chemical compounds and grinding, in order to provide fine granulometry and a lighter color, consequently reducing the micronutrient content. It is widely used in baking.

Brown sugar is an unrefined sugar with a strong flavor (molasses) and differs from white sugar mainly because of its dark coloration and the lower percentage of sucrose (McGee, 2012). It has less energy value compared to refined sugar; however, it has greater mineral content, such as calcium, iron, magnesium, and potassium. Brown sugar has a proximate composition, mineral salts, and organic components very close to that of sugarcane juice (Gbabo, Wada, & Akinsanya, 2004).

Raw sugar is a type of granulated sugar of yellowish color and is characterized by presenting crystals wrapped by an adherent honey film. It goes through a slight refinement similar to crystal sugar. The essential distinction between the two processes is related to the clarification phase of the broth. For raw sugar, clarification is carried out using lime milk. While for white crystal sugar, lime milk and sulfur dioxide are both used. Sulfurous anhydride is obtained by the combusting of mineral sulfur (Prati & Moretti, 2010). Raw sugar is the sugar at the point before the molasses is removed in the processing of sugar cane (Marcus, 2013).

Coconut sugar is made in a rustic manner without chemicals, becoming a more natural and healthier alternative to other types of sugars. Coconut sugar sweetens like regular white sugar. It does not have fewer calories but is more beneficial to the human organism. Coconut sugar has been a part of the culinary and herbal group used in Southwest Asia for a long time (Van Esterik, 2008), especially by people who are looking for a healthier diet or who suffer from diabetes. It is one of the healthiest sugars and can bring numerous health benefits, besides being nutritious it has a high amount of potassium, magnesium, zinc, and iron and complex B vitamins (B1, B2, B3, and B6; Apriyantono, Aristyani, Lidya, Budiyanto, & Soekarto, 2002). Coconut sugar is produced from the sap of palm flowers. The sap is boiled to lose water until the formation of crystals.

This study aimed to evaluate the influence of different types of sugars (crystal, icing, raw, brown, and coconut) on the quality of guava jams. Physical, physicochemical, and sensory properties of guava jams were assessed to identify the most feasible type of sugar to produce healthier jams compared to the traditional formulation with white crystal sugar.

Material and methods

Materials

White crystal, icing, raw, brown, and coconut sugars were purchased from a local market in Lavras (Minas Gerais state, Brazil). Ripe guava fruits (*Psidium guajava*) were harvested from a local farm (Mato Dentro) between January and February, 2017 (Itutinga, Minas Gerais state, Brazil - Latitude: -21.2983, Longitude: -44.66; 21° 17′ 54″ South, 44° 39′ 36″ West). High-methoxylation (HM) pectin (> 50% esterification degree - Danisco, São Paulo state, Brazil) was used.

Manufacturing of guava jams

Fruits were placed in plastic trays and transported to the vegetable processing pilot plant. Manual and visual selections of improper (physical and microbiological damages) fruits were carried out. They were then washed, sanitized (sodium hypochlorite 0.02 mg L^{-1} for 30 min.), rinsed with tap water, manually peeled, and frozen at -18°C until the manufacturing. Before processing, guava fruits were unfrozen at 5°C and processed in an industrial blender (4 L) at 3,500 rpm (PDLI LS-4, Metalúrgica Siemsen, Brusque, Brazil). The fruits were blended with water at the ratio 1:1 w w^{-1} (pulp:water). The obtained juice was sifted (0.7 mm) to eliminate fibers and seeds. A completely randomized design (CRD) with four replicates per treatment was performed. The formulations had 60 juice, 38.5 sugar, and 1.5% pectin. In the case of concentrators operated at atmospheric pressure, the addition of pectin powder must be carried out halfway through the end of the cooking process, which avoids the risk of degradation due to overcooking. In vacuum processing, it can be added at the beginning of the process, along with the other ingredients. Commercial pectin powder should not be added in pure form but mixed with a portion of sugar and added to the juice during the cooking process. The pulp of the fruit was slowly mixed with sugar and pectin in a jacketed steam kettle. The heating stopped when 65 ºBrix was reached. This measure was taken by using a refractometer (Instrutherm, RT-82, São Paulo state, Brazil). The product was properly pasteurized (350 mL glass jars with metal lids) and stored at 7ºC. Due to the natural acidity of guava fruit (pH 3.5 ± 0.5) no acid was added. Five formulations were produced, where only the sugar type was changed (white crystal - 1,680 kJ 100 g^{-1}, icing - 1,680 kJ 100 g^{-1}, raw - 1,700 kJ 100 g^{-1}, brown - 1,673 kJ 100 g^{-1} or coconut - 1,600 kJ 100 g^{-1}).

Proximal composition

Moisture, lipid, protein, ash, and dietary fiber content were assessed in the jelly according to Association of Official Analytical Chemists (AOAC, 2016) performed in four replicates.

Acidity, pH, water activity (A_w) and total soluble solids (TSS)

Acidity, pH, A_w, and TSS were determined in the jelly according to the AOAC (2016), performed in four replicates.

Instrumental color parameters

Color parameters (L*, a*, b*, C*, and °Hue) of jams were determined with the aid of a Minolta colorimeter (CR 400, Minolta, Tokyo, Japan) with D65 illuminant. Results were expressed as the CIELab parameters. Ten measurements were taken.

Total phenolic compounds and antioxidant activity

Extracts were obtained according to (Larrauri, Rupérez, & Saura-Calixto, 1997). The yield of total polyphenols was determined according to the Folin-Ciocalteu's assay (Singleton & Rossi Jr., 1965) and the antioxidant activity was assessed through the DPPH• scavenging method (Brand-Williams, Cuvelier, & Berset, 1995).

Texture profile analysis

Texture profile analyses (TPA) of the jams were carried out using a texture meter (Stable Micro System, TA.HD plus, Godalming, United Kingdom) to determine hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness, according to (Souza et al., 2014) with modifications. A P-6 probe was used for the analysis which was operated at pre-test speed of 2.0 mm s^{-1}, test speed of 5.0 mm s^{-1}, post-test speed of 10.0 mm s^{-1}; penetration distance of 20 mm; the time interval between penetration cycles of 5.0 s, and trigger force of 10 g. The data were obtained through Exponent Lite software (version 6.1.4.0) (Stable Micro System, Godalming, United Kingdom).

Rheological behavior

The rheological behavior of jams was measured using a rheometer (PaarPhysica, MCR 101, Ostfildern, Germany). Newton's Law, Power Law and Herschel-Bulkley models were adjusted to rheological data.

Fourier transform infrared (FTIR) spectroscopy

The functional groups of the samples were identified by FTIR spectra (PE-RX1, Perkin-Elmer Corp., Norwalk, USA - Basu, Shivhare, Singh, & Beniwal, 2011).

Microbiological control

The microbiological analyses assessed the presence of thermotolerant coliforms at 45°C (absence in 1 g), molds and yeasts ($\leq 10^3$ UFC g^{-1}), and *Salmonella* spp. (total lack in 25 g - Salfinger & Tortorello, 2015).

Sensory analysis

Sensory acceptance of guava jams produced with different types of sugar was performed with 100 untrained adults (> 18 years old), as recommended for laboratory-scale tests (Stone, Bleibaum, & Thomas, 2012). Instructions on the sensory tests were given to each participant who provided a statement on informed consent. Panelists were asked to evaluate coded samples of five different selected formulations for a degree of liking, on a 9-point scale ('extremely liked' to 'extremely disliked'). This project was submitted to the Ethics Research Committee (CAAE 20489913.0.0000.5148).

Statistical analysis

Analysis of variance (ANOVA) was carried out, and differences amongst means were evaluated using Scott-Knott's test ($p < 0.05$). Data were also analyzed by the Principal Component Analysis (PCA) to correlate the physicochemical and textural characteristics of different jam formulations. All data were statistically analyzed using the RSTUDIO software version 3.2.0.

The data obtained in the rheological analysis were fitted to the models using linear regression, using the statistical software Statistical Analysis System (SAS University Edition, Cary, USA, 2016).

Results and discussion

Proximal composition, physicochemical, total phenolic compounds, and antioxidant analyses

Chemical and physicochemical parameters of guava jams elaborated with different types of sugars are shown in Table 1. The nutritional aspect of food is directly related to the health of consumers and the promotion of healthier foods, a public health strategy. Thus, the nutritive value of guava jams with different types of sugar was evaluated, and it was found that jam with raw sugar presented the highest moisture and fiber contents and the lowest carbohydrates content. According to (Food and Agriculture Organization [FAO], 1997), guava jams produced in this study are high in dietary fiber (≥ 6%), which is a component that is highly envisioned by health-conscious consumers, as it assists in the digestion by improving the peristaltic movements and lowers plasmatic cholesterol (Wu et al., 2015).

Raw and brown sugar jams also presented the lowest lipid content, which, in addition, can be considered as fat-free food (FAO, 1997). Raw and crystal sugar jams presented the highest protein content; however, these jams cannot be considered a source of this macronutrient (≥ 10%) (FAO, 1997). It is known that the ash content indicates the content of minerals the sample has; amongst the jams studied, brown sugar jam was the most relevant source of these compounds. Kochhar (2016) also analyzed the nutritive value of pink-fleshed guava jam elaborated with white crystal sugar (1:1 w w^{-1} pulp:sugar); however, the seedless pulp was used instead, which can explain the lower fiber content (0.92 - 2.16%) compared to the product developed in this study. Regarding the other nutrients, the last author reported different values from the present study (0.019 - 0.042% of lipids; 0.19 - 0.29% of protein; 0.17 - 0.32% of ash). Due to its high moisture content (> 29%), it becomes easy to proliferate mold when in contact with the external environment.

Through color analysis, it was possible to observe that the use of different types of sugar for jam elaboration caused a significant difference in the coloration of the final products. The addition of darker sugars, such as coconut, and raw sugars, decreased the luminosity value (L*), as well as the a* (red versus green) parameter (Table 1). The replacement of crystal sugar by brown sugar caused an elevation on the parameter b* (blue versus yellow), and the addition of coconut and raw sugars lowered this parameter. This trend was also followed by parameter C*. The higher the parameter C*, the better the vivacity of the product color. Therefore, the parameter °H was higher for jams prepared with raw, brown, and coconut sugars. These results reflected the reddish-brown color of the jams. When a* > 0, the fruit presents a tone closer to red, and when a* < 0, the fruit's tone is closer to green. The increase of a* can be attributed to the stage of maturation in which the fruit was harvested, altering the content of anthocyanin, present in greater quantity in the mature fruits, and which is justified by the synthesis of these pigments as chlorophyll degradation occurs (Chitarra & Chitarra, 2005). The value of H°, representative of color tonality, expresses the measure of the average wavelength of light it reflects or emits, defining the color of the object. The H° found for the jams ranged from 46.22 to 57.32. The lowest value represents a higher intensity of the red color, which could be confirmed by the use of white sugars, such as crystal and icing, which kept the redness of the fruit. On the other hand, jams prepared with brown and coconut sugars exhibited the highest values for this parameter, respectively, indicating a darker orange coloration. The chroma parameter allows characterizing the saturation of the global coloration. The values of C* found for guava jams are in the range of 13.64 to 19.63. Lower chroma values indicate paler or less pure colors (Munsell Color, 2007), which was found for brown sugar jam. The jam prepared with icing and raw sugars showed the highest C*, indicating a more vivid and brighter color.

Determination of pH, acidity, A_w, and TSS contributes to the real appreciation of fruit and product flavor. The pH values were high, 3.5 or less is desired. Citric acid should be added in future formulations for better microbiological control. TSS represents the content of soluble sugars, organic acids, and other minor constituents present in fruits. The concentration of these solids, together with the acidity, is one of the most important variables to measure fruit quality, such as the degree of maturation (Cavalini, Jacomino, Lochoski, Kluge, & Ortega, 2006). TSS content in guava jams elaborated with five types of sugar varied from 59 to 63 °Brix, where the crystal sugar jam exhibited the highest TSS content. Most of the treatments presented TSS content below the legal minimum allowed (62 °Brix). Sucrose goes through, in an acidic environment, an inversion process that transforms it into monosaccharides (glucose and fructose), during the processing of jam (Tomotani & Vitolo, 2010). This could have been the reason of the low final TSS content in guava jams. Furthermore, the ideal amount of sugar is essential for gel formation and product conservation; if the final TSS of jam is lower than 65 - 68%, the shelf life is reduced. Damiani et al. (2009), after evaluating the quality of jams formulated with 0, 25, 50, 75, and 100% of guava pulp (*Mangiferaindica* L. cv. Haden) substitution by peel, also observed lower final TSS contents, ranging from 62 to 62.5 °Brix. This content of sugar is relevant to suppress microbial growth, provide shine through pectin setting and sweeten the product (Ali, 2007).

The total titratable acidity ranged from 0.218 to 0.295 g citric acid 100 g^{-1} (Table 1), falling below the range of acidity recommended for most fruit jams (Lago-Vanzela et al., 2011). Melo Neto, Carvalho, Pontes, Barretto, and Sacramento (2013) observed that titrable acidity values in the range of 0.46 to 0.64% for açaí and cocoa honey jams, where the concentration of cocoa honey directly influenced acidity. This trend could also be observed in this work, where the type of sugar influenced the acidity of guava jams. The pH is also an important parameter in determining the growth potential of microorganisms capable of causing deterioration and also in the growth of pathogenic ones. The pH of guava jams ranged from 4.11 to 5.16, and it was a little higher than the suggested range for jams (2.8 to 3.3). Rubio-Arraez, Capella, Castelló, and Ortalá (2016) found a lower pH average for citrus jam (3.5) compared to this study.

The optimum pH value for obtaining conventional jellies is around 3.2, with a variation between 3.00 and 3.40. In low acid media, the fiber network becomes weak, with no liquid phase retention capacity, and the gel becomes weak. In very acidic media, the gel becomes hardened, losing its elasticity and its ability to maintain the structure, and syneresis (water loss) may occur. Another explanation for the action of acid is that, when present in excess, it can cause excessive dehydration, decomposition, or hydrolysis of pectin.

In general, the acidification of the mixture (pulp, sucrose, and pectin) for the preparation of jellies, if necessary, must be carried out at the end of the concentration process, before filling, in order to avoid the destruction of the pectin and the consistency of the gel formed. No acid was added in making the jelly.

Jackik (1988) claims that the pH of jellies should be 3.4, and below 3.0 there is a tendency to syneresis.

A_w was found to be elevated in guava jam (> 0.9), which can be considered a semi-perishable food (0.88 ≤ A_w ≤ 0.96 - Moura, Prati, Vissotto, Ormenese, & Rafacho, 2011). Most of the jams were found to be in this range, except for raw sugar jam, which was the formulation with the highest moisture content (Table 1). According to Moura et al. (2011), traditional jellies have 55 - 60 °Brix and A_w ~ 0.78. Kanwal, Randhawa, and Iqbal (2017) reported a lower A_w range (0.742 - 0.842) for guava jam than the one found in this study, showing that more stable formulations are possible to be achieved without adding preservatives.

Table 1. Proximal composition (g 100 g^{-1} dry basis), physicochemical (wet basis), and texture profile analyses of guava jam with different types of sugar.

Parameter	Crystal	Icing	Raw	Brown	Coconut
Moisture	54.61±4.07b	50.98±1.38b	66.37±0.5a	51.52±2.26b	53.07±1.24b
Lipid	0.14±0.03a	0.05±0.02c	< 0.01d	< 0.01d	0.12±0.0b
Protein	1.07±0.13a	0.86±0.24b	1±0.04a	0.8±0.04b	0.73±0.08b
Ash	0.8±0.02c	0.76±0.03c	1.16±0.02b	1.54±0.04a	0.64±0.02d
Dietary fiber	12.6±0.17c	13.86±0.49b	15.92±0.89a	13.39±0.09b	11.86±1.58c
Available carbohydrates	30.79	33.49	15.54	32.74	33.58
L*	39.09±0.4b	36.57±0.25c	40.97±0.14a	28.89±0.11e	31.34±0.55d
a*	13.52±0.85b	15.85±0.88a	15.18±0.19a	9.35±0.48c	12.53±0.73b
b*	8.67±0.57c	11.58±0.41a	10.85±0.33a	9.93±0.36b	11.83±0.66a
C*	16.06±1.02c	19.63±0.94a	18.67±0.34a	13.64±0.58d	17.24±0.96b
°H	57.32±0.54a	53.83±0.75b	54.45±0.6b	43.27±0.91d	46.65±0.98c
Acidity (g CA 100 g^{-1})	0.22±0.01c	0.22±0.01c	0.23±0.0b	0.29±0.0a	0.22±0.0c
pH	4.16±0.01d	4.11±0.01e	4.46±0.01c	5.16±0.01a	5.14±0.01b
A_w	0.952±0.004c	0.948±0.002c	0.981±0.006a	0.946±0.005c	0.967±0.007b
Soluble solids (°Brix)	62.75±0.5a	60±0.0b	59±0.0c	60±0.0b	60±0.0b
TPC (mg GAE 100 g^{-1})	93.27±3.37c	95.78±2.77c	121.28±4.9b	162.28±15.5a	74.66±3.65d
DPPH• scavenging activity (%)	28.57±2.93d	66.76±2.93b	62.1±4.02c	79.87±3.51a	62.83±6.7c
Hardness (N)	0.78±0.02c	0.82±0.02b	0.56±0.01d	1.18±0.05a	0.84±0.03b
Adhesiveness (N s)	-1.25±0.03b	-1.32±0.01b	-0.68±0.04c	-2.05±0.09a	-1.25±0.06b
Springiness	0.97±0.01a	0.98±0.01a	0.98±0.0a	0.96±0.02a	0.98±0.01a
Cohesiveness	0.85±0.03a	0.86±0.02a	0.82±0.02a	0.83±0.02a	0.83±0.02a
Gumminess	0.66±0.03b	0.7±0.02b	0.46±0.01c	0.98±0.06a	0.7±0.04b
Chewiness	0.64±0.04b	0.69±0.03b	0.45±0.01c	0.95±0.08a	0.68±0.04b

CA: citric acid; TPC: total phenolic compounds; GAE: gallic acid equivalent. Means followed by the same letter in the same row are not statistically different according to the Scott-Knott's test ($p < 0.05$).

The water activity (Aw) for jellies must be less than 0.95 in order to prevent the growth of microorganisms. According to Pimentel, Dias, Ribeiro-Cunha, and Glória (2002) the water activity above 0.90 allows the growth of bacteria. Aw values found in this study are above the desirable value.

The soluble solids content was less than desired. The ideal sugar concentration should be around 67.5 °Brix, because if the jelly's end point is above this value, crystals will be formed; if it goes below, it will result in a softer jelly (Caetano, Daiuto, & Vieites, 2012).

Regarding the bioactivity of jam formulations, it was observed that brown sugar stood out with higher TPC and antioxidant activity (Table 1). According to Jaffé (2012), this sugar contains diverse bioactives that come from the extracted sugarcane raw matter and are the main reason of their biological potential, showing benefits to the health, such as the immunological effect (Damiani, Silva, Asquieri, Lage, & Boasreported, 2012) much lower values for the antioxidant activity and TPC content of araçá (*P. guinnensis*) jam (47.25% and 50.73 mg GAE 100 g^{-1}, respectively) than those found in this study for guava jams.

The work by Kanwal et al. (2017) investigated the influence of different processing methods and ingredient blending techniques to assess the storage stability and consumer acceptability of guava jelly. At zero storage time, TPC and DPPH inhibition activity values ranged from 76.84 - 81.45 mg GAE 100 g^{-1} and 39.50 - 44.09%, respectively. Comparing the works, the TPC values of the present work were close to the work of Kanwal et al. (2017) only when using coconut sugar. Regarding the values of DPPH inhibition activity, all values were different from the cited work.

Guava (Psidium guajava L.) is a source of phenolic compounds (Blancas-Benítez, Pérez-Jiménez, Montalvo-González, González-Aguilar, & Sáyago-Ayerdi, 2018). Considering the amount of TPC in the fresh fruit of approximately 185.46 mg GAE 100 g^{-1}, according to Kanwal et al. (2017), it is observed that the values in the guava jelly in the present work were lower. The reduction in total phenolics during jelly cooking may be due to the breakdown of cell structure during fruit processing.

For Kanwal et al. (2017), the antioxidant activity of inhibition of guava in natura is approximately 87.4%, a value lower than that found for guava jams in the present work. Temperature has an influence on the rate of antioxidant loss, in addition to the development of antioxidant products from the Maillard reaction during jelly preparation.

Texture profile analysis (TPA)

The characteristics of food surface texture are one of the first quality parameters that consumers evaluate. The texture is composed of a set of sensory attributes of great importance, considering that they determine or influence the acceptance or rejection of the food. The experimental values of these parameters are listed in Table 1.

The parameters of hardness, adhesiveness, gumminess, and chewiness showed a significant difference ($p < 0.05$) among jams formulations (Table 1), while differences for springiness ($p > 0.05$) and cohesiveness ($p > 0.05$) were not observed. The lowest and highest values of hardness (ranging from 0.56 to 1.18 N), gumminess (ranging from 0.46 to 0.98), and chewiness (ranging from 0.45 to 0.95) were observed for jams with raw and brown sugar, respectively. This could be attributed to the differences between the physicochemical characteristics of sugars; once brown sugar has higher levels of reducing sugars than crystal, raw, and icing sugars (Bettani, Lago, Faria, Borges, & Verruma-Bernardiand, 2014) mixtures with monosaccharides (reducers) form more structured gels than disaccharides (non-reducers) (Menezes et al., 2009). Mechanical ‘properties’ of foods are ‘connected’ to food ‘structure, because the ingredients modify the texture’, and variations in ingredients frequently bring on shifts in the jam’s gel network that are often noticed by the end-users (Basu & Shivhare, 2010).

Principal component analysis (PCA)

According to the PCA (Figure 1) and Table 1, it can be seen that the jam produced with brown sugar had higher acidity than the other types of sugar. In spite of the fact that all jams have gone through the same processing time, intending to reach 65° Brix, it was observed that the crystal sugar jam had a higher correlation with TSS. While the jam with raw sugar had the lowest TSS. The PCA showed an interesting trend; the parameters H° and b* are inversely correlated, meaning that the higher the H°, the lower is the b*. PCA reveals that jams with crystal and icing sugars are more correlated with parameter a*, as they have more of red color, while brown and raw sugars jams are more correlated with b*, as expected. The texture parameters are essential for a proper evaluation of jam since it is believed that textures are the result of combinations of ingredients and flavors in conjunction with the preparation method. To further correlate the TPA data with the different types of jams, a PCA was performed. Many parameters can influence the final texture of jams, including sugar content, soluble pectin, pH, and acidity (Souza et al., 2014). It was observed that brown sugar resulted in a jam with the highest resilience, and presented the highest pH, a phenomenon that was also observed by Dias, Curi, Pio, Bianchini, and Souza (2018) for white crystal sugar cambuci (*Campomanesia phaea*) jam. Menezes et al. (2009) reported that the reduction of citric acid led to an increase in cohesiveness and adhesiveness of guava (Pedro Sato cultivar) preserves, showing its influence on the firmness of the products. The latter behavior could be observed for crystal sugar in this study, which presented low acidity and was correlated with cohesiveness. Springiness and adhesiveness are correlated parameters, and jams elaborated with raw, coconut, and icing sugars exhibited a higher correlation with them. Springiness was the only parameter that did not present significative differences (p > 0.05) amongst the treatments, where brown and raw sugar jams showed the lowest values. It was also possible to infer that chewiness and gumminess are highly correlated parameters.

Rheology

The flow behavior of jam is an essential property to evaluate the spreadability, thickness, uniformity, and mechanical properties of the product. The model that best fitted the experimental data of all treatments was the Power Law, with a higher coefficient of determination ($0.9994 < R^2 < 0.9998$) values and lower root mean square error (RMSE < 2.0848) values than the Newton's Law and Herschel-Bulkley (HB) models. Also, jams presented a shear-thinning behavior, due to the flow behavior index values (n) < 1 and the consistency index values (K) > 0, as shown in Table 2. The variation of the apparent viscosity of jams, with shear rates ranging from 0 to 500 s^{-1}, is shown in Figure 2. An increase in the shear rate was observed to decrease the apparent viscosity, a characteristic of shear-thinning products. The viscosity reduction with an increasing shear rate happens since the molecules of the solutions at rest are unsettled, and as stress is put in, they begin to become settled. Thus, high applied pressure (stress) produced higher settling, therefore, lower apparent viscosity. Mango jam exhibited pseudoplastic flow with a yield stress, and the HB model well described the rheological behavior of mango jam over a wide range of sugar and pectin concentration, pH, and temperature (Basu et al., 2011).

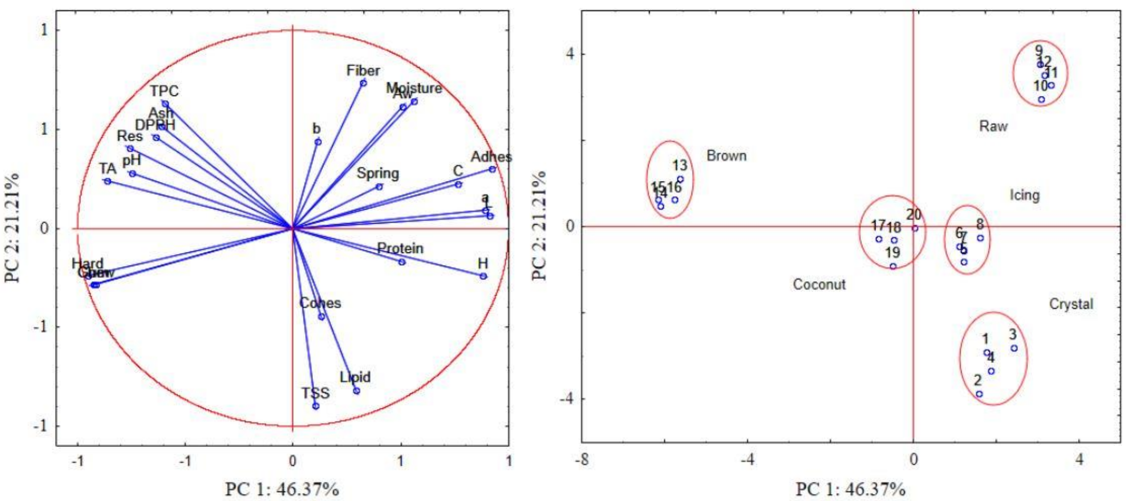

Figure 1. Principal component analysis of guava jam elaborated with different types of sugar. Adhes: adhesiveness; Chew: chewiness; Cohes: cohesiveness; Gum: gumminess; Hard: hardness; Res: resilience; Spring: springiness; TA: total acidity; TPC: total phenolic compounds; TSS: total soluble solids.

Table 2. Power Law model parameters of guava jam with different types of sugar.

Treatments	K (Pa s^n)	n (-)	RMSE	R^2
Crystal	18.5958	0.4320	1.0382	0.9997
Icing	21.3164	0.4572	2.0848	0.9994
Raw	7.3309	0.553	0.8421	0.9998
Brown	19.22962	0.4509	1.0883	0.9998
Coconut	7.5180	0.5125	0.9908	0.9995

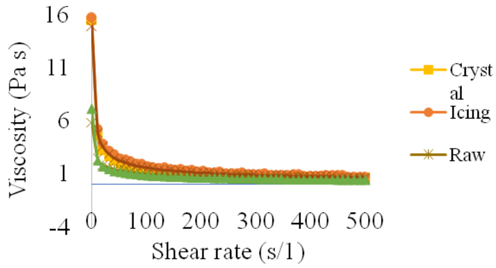

Figure 2. Variation of the apparent viscosity of guava jams with different types of sugar (shear rates ranging from 0 to 500 s^{-1}).

Fourier transform infrared (FTIR) spectroscopy

Jams with different types of sugars have similar spectral bands; however, there are tenuous differences in the intensities of the peaks (Figure 3). The jam made with crystal sugar showed the least intense peak at around 3,352 cm^{-1} for the O-H stretching. The other jam samples showed almost identical and broad peaks in this region, representing increased intramolecular hydrogen bonding between water (hydroxyl group) and the stretching vibration of N-H bonds of crystalline molecules. sp^3 C-H stretching frequency (2,900 cm^{-1}) was found to be more intense and almost merged in raw and coconut jams, and less severe in crystal sugar jam. This band showed sharp peaks for all types of sugar, except for crystal sugar. The intensity for free COO^- (oxalate - 1,630 cm^{-1}) was lower for crystal sugar, indicating that the chemical nature of both sugars is similar. O-C-H, C-C-H, and C-OH bending vibrations presented sharp peaks at 1,480 cm^{-1}, which were similar for coconut and raw sugar jams, and less intense for crystal sugar. The peaks at 900 - 1,150 cm^{-1} are assigned to the C-C and C-O stretching vibrations, which were similar for coconut and raw sugar jams, and also for crystal and brown sugar jams. The C-O band of icing sugar is the least intense; this could be due to the removal of C-C bonds during processing. The peaks at around 400 cm^{-1} indicate an anomeric region. The formation of the polymeric network of the pectin chain is caused by hydrogen bonds and intermolecular hydrophobic interactions (Basu et al., 2011). It may, therefore, be inferred that guava jam prepared with raw and brown sugars were more rigid than the other ones. These spectral features are indicative of a healthy network formation in the jams manufactured with brown, coconut, and raw sugars. This observation agrees with the results of the textural and rheological analysis, in which the jam manufactured with brown sugar exhibited maximum hardness.

Microbial and sensory analysis

Microbiological analyses were carried out before sensory analysis and tested negative for coliform *Salmonella*, and molds/yeasts in all guava jam samples, indicating the quality of the product and that the process was carried under proper sanitary conditions. Table 3 shows the sensory properties values of guava jams. A significant difference ($p \leq 0.05$) was observed for all attributes. It was observed that the jam produced with white crystal, icing, and raw sugars presented the highest scores for all sensory attributes (‘moderately liked’ to ‘liked very much’), as well as for overall impression and purchase intention. However, the color, aroma, and flavor of these sugars are already more common to the population palate. Raw sugar is only slightly refined, no chemical additive is added to it, it is the most nutritive sugar, and it was among the three most well evaluated sugars (Marcus, 2013). Jams produced with brown sugar and coconut sugar, however, obtained the lowest sensory scores (Table 3). A trend that was also observed by Curi et al. (2017) for physalis (*Physalis peruviana*) jellies. Brown and coconut sugars were characterized by being the healthiest and most nutritionally rich sugars, probably due to the absence of added chemical additives. However, jams with these sugars did not result in good sensory acceptance, which is the most likely reason why they obtained lower acceptance scores regarding the color attribute. The characteristic and robust flavor of these sugars may also have contributed to the low sensory acceptance and purchase intention. The burnt coconut taste characteristic of coconut sugar and the strong taste similar to the sugarcane juice typical of brown sugar might have masked the taste of guava, and as such, did not please the tasters. The brownish colors characteristic of these sugars also did not please the tasters, which are already used to the typical red color of guava. Overall, brown and coconut sugars, which are the most nutritive ones, did not give rise to jams with good acceptance. On the other hand, it could be noticed that white crystal and icing sugars, generally used in jams, are replaceable by raw sugar. The latter has better quality and allows the production of jams with good acceptance when compared to the conventional ones.

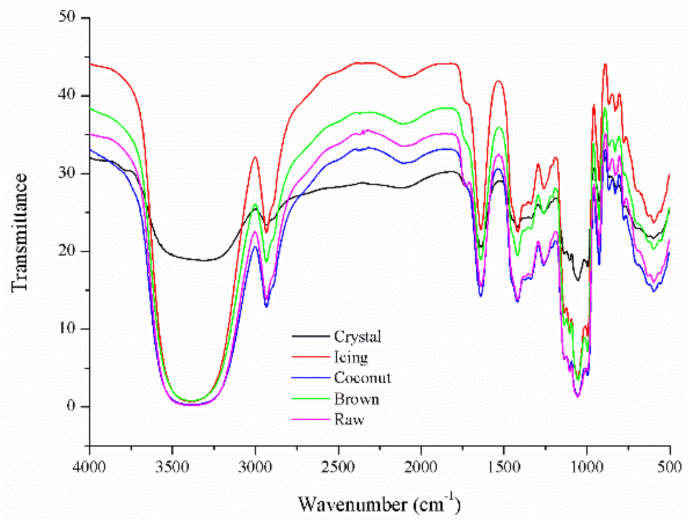

Figure 3. FTIR spectra of guava jam with different types of sugar.

Table 3. Average grades and average test for the sensory attributes evaluated in guava jam obtained from different types of sugars.

Formulations	Sensory Parameters					
	Color	Aroma	Flavor	Consistency	Global impression	Purchase intention
Crystal	6.77[a]	7.78[a]	7.81[a]	7.46[a]	7.51[a]	4.31[a]
Coconut	4.95[b]	5.07[b]	5.28[b]	6.90[a]	5.29[b]	2.44[b]
Icing	6.96[a]	7.29[a]	7.51[a]	7.36[a]	7.24[a]	4.11[a]
Brown	4.85[b]	5.53[b]	4.74[b]	6.40[a]	5.18[b]	2.42[b]
Raw	7.07[a]	7.21[a]	7.24[a]	7.32[a]	7.19[a]	3.89[a]

The mean values with the same lowercase letters in the column indicate that there is no significant difference between the samples ($p \leq 0.05$) from the significant Tukey test.

The internal preference and the PCA maps for all treatments and the attributes color, aroma, consistency, taste, overall impression, and purchase intention are presented in Figure 4. Consumers are represented by vectors. Therefore, a higher concentration of vectors near the sample suggests a greater acceptance. It was observed that the two main components (PC1 and PC2) explained more than 70% of the acceptance of data variance for almost all attributes, except for the consistency attribute (Figure 4C), with 67.09%. By the arrangement of the five formulations on the map (Figure 4), the formation of three distinct groups was suggested. It was verified that the majority of consumers, represented by the vectors, are in the direction of the jams produced with crystal, icing, and raw sugars, showing that these sugars obtained the highest scores and the greatest sensorial acceptance for the aroma attribute. The jams produced with coconut and brown sugar formed two other groups, which may be due and related to the intrinsic characteristics of each raw material since the processing time and method was the same for all treatments.

Brown and coconut sugars did not contribute to good sensory acceptance, probably because of the consistency (less viscous). However, coconut sugar was much more pleasing regarding the consistency attribute than brown sugar. The coconut sugar extraction process is made from coconut palm flowers, whose nectar is removed and heated, becoming a thick caramel. Its flavor is typical of coconut, and it presents itself as the healthiest sugar. It is not refined, so it maintains complex B vitamins, zinc, iron, and magnesium. Also, it has a much lower glycemic index than refined sugar, promoting a slower release of energy to the body, avoiding peaks of glucose in the bloodstream (Apriyantono et al., 2002). On the other hand, raw sugar undergoes a light refinement process, but without chemical additives and with it maintains a caramel color, coarser, and slightly moist grains. It is considered the healthiest among the three most accepted, and its benefits are observed from the nutrients that are present in it. In its composition, there are vitamins of complex B, calcium, magnesium, phosphorus, and potassium (Marcus, 2013).

Some tasters also expressed interest in buying the jam elaborated with brown sugar. The coconut sugar gave rise to a darker jam, presenting the lowest values of L*, a*, and b*, according to the PCA (Figure 1) and Table 1, thus, with a greater intensity of browning, which is probably the reason why it obtained the lowest scores of sensory acceptances regarding color and overall impression. The most accepted jams were more transparent and with more intense red/yellow color. Brown and coconut sugar were the most unsatisfactory jams, as their color was darker and with low acidity (higher pH values).

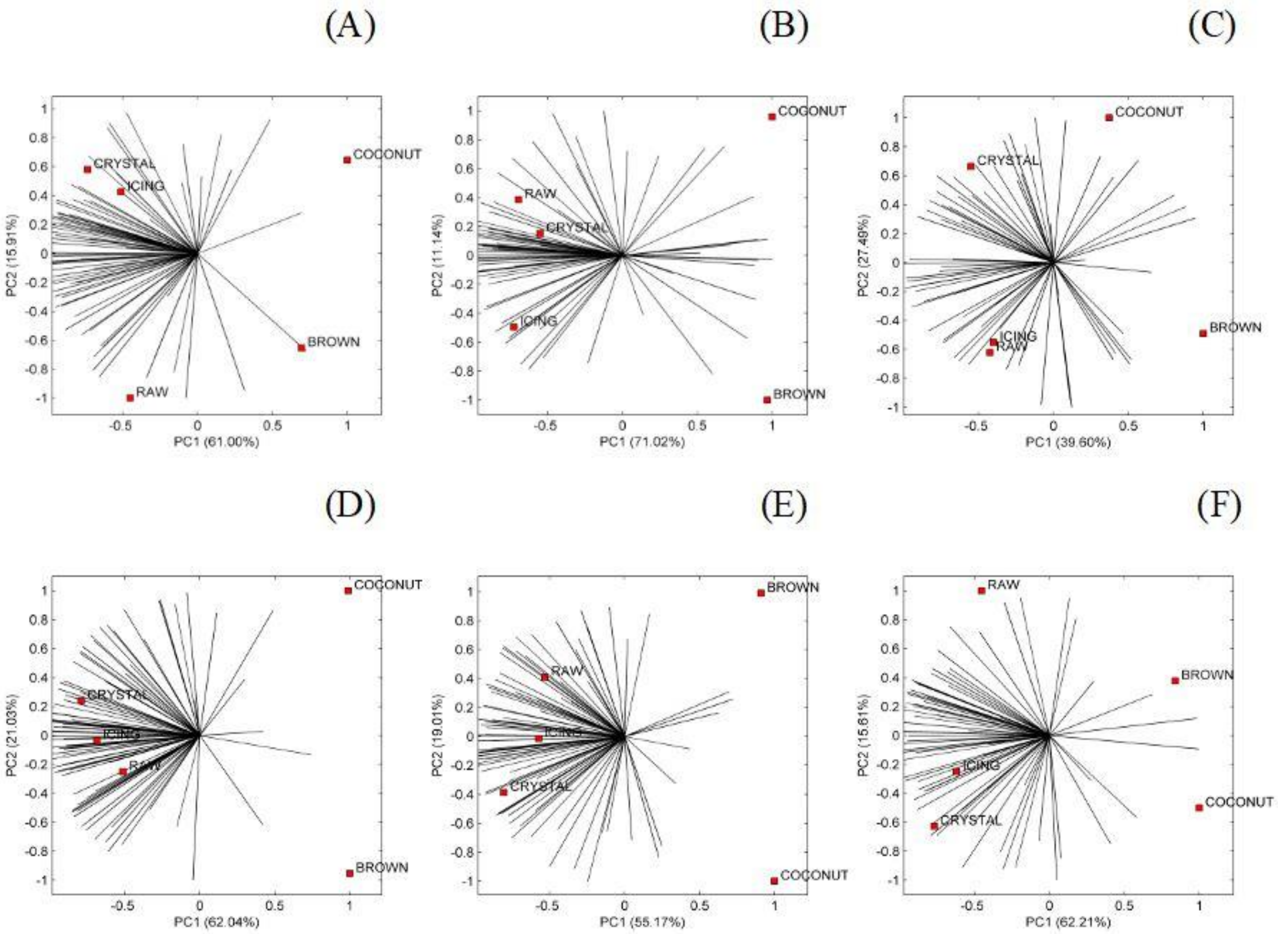

Figure 4. Internal preference maps for the sensory acceptance of guava jam with different types of sugar. Aroma (A), color (B), texture (C), taste (D), global impression (E), and purchase intention (F).

Brown sugar jam showed the highest texture and soluble solids values. Therefore, the authors observed that the consumers preference for a more transparent jam and, as a result, a jam that resembles its raw material (the fruit) color (guava). Also, they showed preference to softer, acid, and less sweet jams. Similar results were observed by Curi et al. (2017).

Conclusion

The sugar type showed a significant effect on the sensory acceptance of guava jam. Jams with higher sensorial quality were formulations produced with conventional sugars - white crystal and icing sugars - and also with raw sugar. However, one can easily substitute the crystal and icing sugars, mostly used for jams manufacturing, by raw sugar, which has good nutritional quality and gives rise to jams as well-accepted as the conventional ones, indicating that the consumption of these products should be encouraged.

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