Effects of storage time and different sugar types on color characteristics, bioactive compounds, and antioxidant capacity of jaboticaba jellies

Efeitos do tempo de armazenamento e de diferentes tipos de açúcares nas características de cor, compostos bioativos e capacidade antioxidante de geleias de jabuticaba

Efectos del tiempo de almacenamiento y diferentes tipos de azúcar en las características de color, compuestos bioactivos y capacidad antioxidante de jaleas de jaboticaba

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ABSTRACT
The objective of this study was to evaluate the effects of storage time and the use of different sugar types (crystal, refined, demerara, brown) on color characteristics, bioactive compounds, and antioxidant capacity of jaboticaba jellies. All analyses (microbiological, color, anthocyanins, vitamin C, total phenolic compounds, and antioxidant capacity by ABTS, DPPH, and β-carotene/linoleic acid systems) were performed for 120 days. The results were evaluated by means test and Pearson correlation. It was found that the sugars used in preparation and storage influenced the characteristics of jaboticaba jellies, and mold and yeast growth remained within the standards allowed by Brazilian legislation. All jellies were darkened during storage. Bioactive compound degradation was observed, and antioxidant capacity was reduced. Positive correlations were observed. Thus, demerara sugar, even though it does not provide bright colors in jellies, is the most beneficial for the production of jaboticaba jellies, due to the presence of nutritional compounds.

Keywords: stability, white sugar, demerara sugar, brown sugar.

RESUMO
O objetivo deste estudo foi avaliar os efeitos do tempo de armazenamento e do uso de diferentes tipos de açúcares (cristal, refinado, demerara, mascavo) nas características de cor, compostos bioativos e capacidade antioxidante de geleias de jabuticaba. Todas as análises (microbiológicas, cor, antocianinas, vitamina C, compostos fenólicos totais e capacidade antioxidante pelos sistemas ABTS, DPPH e β-caroteno/ácido linoléico) foram realizadas durante 120 dias. Os resultados foram avaliados pelo teste de médias e correlação de Pearson. Verificou-se que os
açúcares utilizados no preparo e armazenamento influenciaram nas características das geleias de jaboticaba e o crescimento de fungos e leveduras permaneceu dentro dos padrões permitidos pela legislação brasileira. Todas as geleias ficaram escurecidas durante o armazenamento. Foi observada degradação dos compostos bioativos e a capacidade antioxidante foi reduzida. Correlações positivas foram observadas. Assim, o açúcar demerara, mesmo não proporcionando cores vivas nas geleias, é o mais benéfico para a produção de geleias de jaboticaba, devido à presença de compostos nutricionais.

**Palavras-chave:** estabilidade, açúcar branco, açúcar demerara, açúcar mascavo.

**RESUMEN**

El objetivo de este estudio fue evaluar los efectos del tiempo de almacenamiento y el uso de diferentes tipos de azúcar (cristal, refinada, demerara, morena) sobre las características de color, compuestos bioactivos y capacidad antioxidante de jaleas de jaboticaba. Todos los análisis (microbiológicos, color, antocianinas, vitamina C, compuestos fenólicos totales y capacidad antioxidante por los sistemas ABTS, DPPH y β-caroteno/ácido linoléico) se realizaron durante 120 días. Los resultados se evaluaron mediante la prueba de medias y la correlación de Pearson. Se comprobó que los azúcares utilizados en la preparación y el almacenamiento influyeron en las características de las jaleas de jaboticaba, y el crecimiento de mohos y levaduras se mantuvo dentro de los estándares permitidos por la legislación brasileña. Todas las jaleas se oscurecieron durante el almacenamiento. Se observó degradación de los compuestos bioactivos y reducción de la capacidad antioxidante. Se observaron correlaciones positivas. Así, el azúcar demerara, aunque no proporcione colores brillantes en las jaleas, es el más beneficioso para la producción de jaleas de jaboticaba, debido a la presencia de compuestos nutricionales.

**Palabras clave:** estabilidad, azúcar blanca, azúcar demerara, azúcar morena.

**1 INTRODUCTION**

Jaboticaba (*Myrciaria* sp) is a fruit tree native to Brazil that belongs to the Myrtaceae family (Wu et al., 2013). Its fruits, are characterized by a globose berry-like appearance, almost black reddish skin, whitish mucilaginous pulp, bittersweet flavor, and one to four seeds (Wu et al., 2013; Zhang et al., 2018). In addition to exhibiting high antioxidant activity, it has high levels of anthocyanins and phenolic compounds and is considered a promising source of dietary ellagic acid derivatives (Wu et al., 2013). The production of fruit-based products, such as jellies, vinegar, wine, and liquor, involve viable, innovative, and functional practices that can be used to conserve highly perishable fruits (Santos et al., 2020; Zhang et al., 2021).

Sucrose is known to be a good protector of anthocyanins, especially at high concentrations (Tsai et al., 2004). In the manufacture of jellies, sucrose is commonly used in the form of refined white crystals (Chung et al., 2013). However, mineral losses occur during
refining (Mendonça et al., 2000). In addition, clarifying agents are used in its preparation, which can reduce nutritional quality (Curi et al., 2017). Demerara and brown sugars, extracted from sugar cane, are two more natural sugar options over traditional white sugar (Curi et al., 2017). Demerara sugar is an intermediate between refined and brown sugar (Silva et al., 2009) and is a partially refined sugar that consists of sugar crystals, with some residual molasses, and also can be produced by adding molasses to refined white sugar (Manohar et al., 2014). Brown sugar has much greater amounts of minerals such as potassium, magnesium, iron and calcium than demerara, in addition to having greater amounts of phenolics than white sugar (Asikin et al., 2014; Asikin et al., 2016). This sugar contains several phytochemicals that are derived from raw sugar cane extracts that are responsible for its biological potential and beneficial effects on human health (Jaffé, 2012).

Despite many advancements, jelly storage stability remains a complex issue due to the numerous factors that can reduce its useful lifetime (Santos et al., 2020). Therefore, the objective of this study was to evaluate the influence of storage time and the use of different types of sugars (refined white, crystal white, demerara, and brown) on the color characteristics, bioactive compounds, and antioxidant capacity of jaboticaba jellies.

2 MATERIALS AND METHODS

The jaboticabas fresh were received and, after selecting the fruits, they were sanitized in a 2.5% sodium hypochlorite solution for 15 min, placed in polypropylene pots, covered with aluminum foil (to avoid loss of nutrients sensitive to light and oxygen), and stored in freezer (-18°C) until use.

The processing of jaboticabas fresh followed the methodology proposed by Pinto et al. (2021). The jaboticaba underwent bleaching at 96 °C for 5 min, with a ratio of 0.5:1 water:jaboticaba. The mixture was then ground in an industrial blender (Tron Master, Catanduva, SP, Brazil) for 60 s. The fruit mass obtained was filtered through a 14 cm diameter nylon sieve to separate peels and seeds from the final aqueous extract. The obtained fruit extract was stored at -18 °C in polypropylene pots wrapped with foil in order to avoid the loss of bioactive compounds and antioxidant capacity due to sensitivity to light and oxygen.

Four formulations of jaboticaba jellies were elaborated, using crystal sugar (Euroçucar, Jaboticabal, SP, Brazil), white refined sugar (União, Barra Bonita, SP, Brazil), brown sugar
(Nayna, Manhuaçu, MG, Brazil), demerara sugar (União, Sertãozinho, SP, Brazil). In addition, high methoxylation pectin (GastronomyLab, Brasília, DF, Brazil) was used. All formulations were prepared in triplicate.

For the preparation of all jellies, a 60:39.5 extract to sugar ratio and 0.5% high methoxylated pectin, according to previous tests and literature data, were used (Scibisz & Mitek, 2009). Each formulation varied only the type of sugar. The jellies were prepared in an open pan heated by direct flame. For the jelly preparations, sugar was added to the jaboticaba extract. After boiling, pectin was added. At the end of the process, when the soluble solids reached 65 °Brix (measured in a portable refractometer model RT-82, Higmed, Tatuapé, SP, Brazil), the heating was stopped. The jellies were hot packed in previously sterilized glass jars, sealed with sterilized screw caps, cooled to room temperature and stored in a temperature-controlled chamber at 25°C.

Mold and yeast populations were determined using PDA (Potato Dextrose Agar) acidified with 10% tartaric acid. The plates were incubated for 48 h at 25 °C, examined for yeast and mold colonies (CFU/g) and compared with the standards established by DRC n° 12 (Brazil, 2001).

The color of the jellies was determined according to the method described by Gennadios et al. (1996). The values of L*, C*, and °h were determined with a Konica Minolta colorimeter model CR 400, working with D65 (daylight) and using CIELab standards, in which L* ranges from 0 (black) to 100 (white), C* varied between 0 (white and/or gray) and 60 (vivid and/or intense colors), and °h varied from 0 (red) to 270 ° h (blue). The analyses were performed in quadruplicate.

The ascorbic acid content analysis was performed by titration with 2,6-dichlorophenolindophenol (DCFI), as described by Benassi & Antunes (1988). Results were expressed in mg of ascorbic acid/100 g of fresh weight.

Total monomeric anthocyanin content (TMAC) was estimated by the pH differential method (Wrolstad, 1976) using the UV–vis spectrophotometer. Absorbance was measured at 510 nm and 700 nm in buffers at pH 1.0 and 4.5 using equation 1.

\[
(1) \ A = (A_{510} - A_{700})_{PH1.0} - (A_{510} - A_{700})_{PH4.5}
\]

With:
A molar extinction coefficient of 29,600. Results were expressed as mg of cyanidin-3-glucoside/100 g of fresh weight.

The extracts for the analysis of phenolic compound and antioxidant capacity were prepared according to the method described by Larrauri et al. (1997).

Phenolic compounds were estimated following the method of Folin-Ciocalteu (Waterhouse, 2002), the absorbance was read at a wavelength of 750 nm, and results were expressed as mg of gallic acid equivalent/g of fresh weight.

For the determination of the antioxidant capacity by the ABTS radical method, the methodology reported by Re et al. (1999) was used. The results are expressed as micromoles of trolox equivalents (TEs)/g of fresh weight.

DPPH free radical scavenging ability was carried out according to Brand-Williams et al. (1995). The results are expressed as EC$_{50}$ (g of fresh mass/g of DPPH).

The antioxidant capacity analysis by the β-carotene/linoleic acid method was performed according to Marco (1968), with a few modifications. The first reading was performed after 2 min of mixing and at intervals and after 120 min at a wavelength of 470 nm. The results were expressed as percent protection against the control.

The experimental design was a complete 4×5 factorial, with three repetitions, and the factors under study included four types of sugars (crystal, refined, demerara, and brown) and five storage durations (0, 30, 60, 90, and 120 days).

The data obtained were evaluated using analysis of variance (ANOVA) and Scott-Knott tests, considering the variable type of sugar and time at the 5% significance level (p ≤0.05) in Sisvar software (Ferreira, 2014). Pearson's correlation was performed using Statistical Package for Social Sciences (SPSS, version 18.0) software to determine the correlation between bioactive compounds and the antioxidant capacity of jaboticaba jellies.

3 RESULTS AND DISCUSSION

Table 1 presents the results of mold and yeast counts in jaboticaba jellies made with different sugars over the storage period.
### Table 1. Mold and yeast counts (log CFU/g) of jaboticaba jellies made with different sugars over the storage period.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>T0</th>
<th>T30</th>
<th>T60</th>
<th>T90</th>
<th>T120</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Crystal Sugar</td>
<td>2.40</td>
<td>2.00</td>
<td>2.79</td>
<td>2.98</td>
<td>3.04</td>
</tr>
<tr>
<td>White Refined Sugar</td>
<td>2.48</td>
<td>2.90</td>
<td>2.95</td>
<td>3.40</td>
<td>3.45</td>
</tr>
<tr>
<td>Demerara Sugar</td>
<td>2.54</td>
<td>2.78</td>
<td>2.93</td>
<td>3.04</td>
<td>3.11</td>
</tr>
<tr>
<td>Brown Sugar</td>
<td>2.54</td>
<td>2.60</td>
<td>2.71</td>
<td>2.78</td>
<td>2.83</td>
</tr>
</tbody>
</table>

Source: Luciana Rodrigues da Cunha

It is expected that over the storage duration, mold and yeasts will grow in the jellies, as observed in Table 1. However, all jellies fell within the standards established by the Brazilian legislation regarding the presence of molds and yeasts, since the count must present a maximum of 10 CFU/g in jelly ready for consumption (Brazil, 2001).

Molds and yeasts have favorable growth conditions during product storage, with respect to the acidic pH, high storage temperatures, high moisture, and the chemical composition of food (Silva et al., 2010).

It was performed out a microbiological evaluation to analyze the impairment of shelf life in foods with a pH below 4.5 (pH range of fruit jellies) (Silva et al., 2010; Souza et al., 2018), since these microorganisms proliferate at a more acidic pH, and the optimum pH for growth is close to 5.0 (Silva et al., 2010). Therefore, despite the different jelly formulations showing favored growth due to chemical composition, such as sugars, vitamins, and minerals (Santos et al., 2020), the development of these microorganisms from the fruit extract was within the limits of the legislation.

This can also relate the microbiological stability of the different jaboticaba jelly formulations with respect to the use of sugar. Notably, sugar prevents the growth of microorganisms through removing the water layer that provides protection to the pectin particles and facilitates agglutination and gelling (Santos et al., 2012). In addition, sugar can increase osmotic pressure, which renders microbiological growth impossible, since the relationship between osmotic pressure and water activity is inversely proportional and, consequently, the less water available to the microorganism, the more its development becomes inhibited (Bolzan & Pereira, 2017).

Table 2 shows the results of the color parameters of the different jaboticaba jelly formulations during storage. The results showed that, during storage, there was light stability for
all evaluated jellies (Table 2). The luminosity (L*) ranged from 12.58 to 20.04, which indicates that the jaboticaba jellies were dark.

Table 2. Values of the color parameters of the different formulations of jaboticaba jellies during storage.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Luminosidade (L*)</th>
<th>Chroma (C*)</th>
<th>°Hue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T0</td>
<td>T30</td>
<td>T60</td>
</tr>
<tr>
<td>White Crystal Sugar</td>
<td>20.04 ± 1.45 Aa</td>
<td>18.58 ± 3.46 Aa</td>
<td>18.04 ± 4.63 Aa</td>
</tr>
<tr>
<td>White Refined Sugar</td>
<td>16.62 ± 4.16 Ba</td>
<td>16.36 ± 3.68 Aa</td>
<td>13.32 ± 2.10 Aa</td>
</tr>
<tr>
<td>Demerara Sugar</td>
<td>12.88 ± 2.63 Ba</td>
<td>16.06 ± 1.60 Aa</td>
<td>13.92 ± 2.35 Aa</td>
</tr>
<tr>
<td>Brown Sugar</td>
<td>14.90 ± 2.97 Ba</td>
<td>18.20 ± 1.88 Aa</td>
<td>16.76 ± 3.34 Aa</td>
</tr>
</tbody>
</table>

Table 2. Values of the color parameters of the different formulations of jaboticaba jellies during storage.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>T0</th>
<th>T30</th>
<th>T60</th>
<th>T90</th>
<th>T120</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13.22 ± 2.48 Aa</td>
<td>8.30 ± 1.52 Ab</td>
<td>6.24 ± 1.76 Bb</td>
<td>3.53 ± 1.46 Ac</td>
<td>15.10 ± 3.70 Bc</td>
</tr>
<tr>
<td></td>
<td>6.58 ± 2.24 Bb</td>
<td>6.60 ± 2.80 Ab</td>
<td>4.64 ± 3.51 Bc</td>
<td>3.13 ± 0.46 Ac</td>
<td>13.47 ± 1.55 Ac</td>
</tr>
<tr>
<td></td>
<td>6.53 ± 1.53 Bb</td>
<td>7.94 ± 2.15 Aa</td>
<td>9.87 ± 1.03 Aa</td>
<td>4.03 ± 0.75 Ab</td>
<td>8.80 ± 1.58 Ba</td>
</tr>
<tr>
<td></td>
<td>1.35 ± 0.68 Cb</td>
<td>5.34 ± 3.91 Aa</td>
<td>6.70 ± 1.14 Bb</td>
<td>1.78 ± 1.23 Ab</td>
<td>4.90 ± 0.72 Ca</td>
</tr>
</tbody>
</table>

Source: Vitória Regina Pinto. Means ± standard deviation followed by the same capital letter in the column and lowercase in the row do not differ by Scott-Knott test at 5% probability, n=4.

Regarding the chroma values (C*), it was observed that over the storage time, all jellies became more vivid in color, except for the jelly with crystal sugar, which remained constant (Table 2). Jellies made with white sugar (crystal and refined) were more vivid than those made with demerara and brown sugar at the end of storage (p ≤ 0.05). This may be due to the process of making demerara and brown sugars, which do not add clarifying agents (Asikin et al., 2016), and these jellies are therefore darker than those with white sugars.

Through the hue angle (°h), it is possible to estimate the position of a sample in a colored solid (Gennadios et al., 1996). According to this solid, samples with values between 330° and 25° are considered red, 25° to 70° orange, and 70° to 100° yellow. Regarding the jellies under study, it was observed that, with the exception of the jelly made with crystal sugar, all presented
changes over the storage time. At the end of the 120 days, jellies made with crystal and brown sugars remained red, while those made with refined and demerara sugars changed in hue from red (T0) to orange.

According to Jiang et al. (2019), monomeric anthocyanins are extremely unstable and can easily degrade into colorless or brown compounds. The stability of monomeric anthocyanins is influenced by several factors, such as pH, temperature, oxygen, light, concentration, presence of copigments, and presence of metal ions and enzymes (Martynenko & Chen, 2016). According to TACO (2011), brown sugar has significant amounts of magnesium, iron, phosphorus, sodium, and potassium in relation to white refined sugar. Thus, it can be inferred that these components may have protected the anthocyanins present in jellies with brown sugar at the end of storage, thus allowing the jellies to remain red.

Table 3 presents the average values for bioactive compounds and antioxidant capacity of the jaboticaba jelly formulations during storage.

<table>
<thead>
<tr>
<th>Sugar</th>
<th>T0</th>
<th>T30</th>
<th>T60</th>
<th>T90</th>
<th>T120</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total anthocyanin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mg of cyanidin 3-glucoside equivalent/100 g of f.w.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Crystal Sugar</td>
<td>14.78 ± 2.52 Ba</td>
<td>8.08 ± 0.85 Bb</td>
<td>10.13 ± 2.09 Ab</td>
<td>5.17 ± 0.85 Bb</td>
<td>7.34 ± 1.62 Ab</td>
</tr>
<tr>
<td>White Refined Sugar</td>
<td>14.38 ± 7.65 Ba</td>
<td>9.78 ± 1.61 Bb</td>
<td>7.44 ± 3.95 Ab</td>
<td>9.67 ± 0.28 Ab</td>
<td>6.76 ± 1.28 Ab</td>
</tr>
<tr>
<td>Demerara Sugar</td>
<td>18.67 ± 1.26 Aa</td>
<td>14.17 ± 0.95 Ab</td>
<td>4.03 ± 2.69 Bc</td>
<td>3.76 ± 0.87 Ab</td>
<td>3.72 ± 1.08 Ab</td>
</tr>
<tr>
<td>Brown Sugar</td>
<td>18.04 ± 1.62 Aa</td>
<td>11.75 ± 1.96 Ab</td>
<td>4.73 ± 1.39 Ab</td>
<td>11.90 ± 1.23 Ab</td>
<td>6.66 ± 0.69 Ac</td>
</tr>
</tbody>
</table>

| **Ascorbic acid (mg/100 g f.w.)** | | | | | |
| White Crystal Sugar  | 39.87 ± 11.84 Aa | 13.57 ± 2.74 Ab | 6.76 ± 0.00 Ac | 6.65 ± 0.00 Ac | 9.20 ± 0.00 Ac |
| White Refined Sugar  | 40.43 ± 5.50 Aa | 12.96 ± 2.88 Ab | 6.53 ± 0.00 Ac | 6.57 ± 0.00 Ac | 9.48 ± 0.00 Ac |
| Demerara Sugar       | 26.05 ± 3.47 Ba | 11.86 ± 0.00 Ab | 6.51 ± 0.00 Ab | 6.56 ± 0.00 Ab | 9.43 ± 0.00 Ab |
| Brown Sugar          | 26.95 ± 5.50 Ba | 13.19 ± 2.66 Ab | 6.46 ± 0.00 Ac | 6.67 ± 0.00 Ac | 9.40 ± 0.00 Ac |

| **Total phenolics (mg GAEs/100 g f.w.)** | | | | | |
| White Crystal Sugar  | 1.28 ± 0.03 Db | 1.55 ± 0.16 Ca | 0.64 ± 0.07 Ad | 1.19 ± 0.06 Cc | 1.11 ± 0.06 Bc |
| White Refined Sugar  | 1.80 ± 0.03 Ca | 1.68 ± 0.14 Bb | 0.54 ± 0.06 Bd | 1.91 ± 0.18 Aa | 1.30 ± 0.05 Ac |
Demerara Sugar | 2.18 ± 0.09 Ba | 2.22 ± 0.08 Aa | 0.55 ± 0.03 | 1.42 ± 0.01 | 1.20 ± 0.03 | 1.07 ± 0.08
Brown Sugar   | 4.86 ± 0.05 Aa | 2.45 ± 0.14 Ab | 0.74 ± 0.07 | 1.37 ± 0.03 | 1.07 ± 0.08

| Antioxidant capacity – ABTS |
| (µmol/g f.w.) |
| White Crystal Sugar | 76.10 ± 1.80 Cb | 42.90 ± 0.65 Aa | 127.04 ± 2.22 Ba | 40.13 ± 0.05 Aa | 52.72 ± 0.09 Bb | 59.85 ± 0.14 Ba | 52.72 ± 0.73 Ac |
| White Refined Sugar | 92.56 ± 1.62 Aa | 40.82 ± 0.65 Bb | 119.86 ± 1.54 Bb | 48.04 ± 0.21 Bb | 52.72 ± 1.22 Bb | 59.85 ± 1.13 Bb | 59.85 ± 1.92 Ba |
| Demerara Sugar     | 119.97 ± 13.84 Aa | 82.39 ± 0.54 Ab | 87.84 ± 0.74 Bb | 47.97 ± 0.36 Bb | 60.83 ± 2.94 Bb | 60.83 ± 1.92 Bb | 60.83 ± 2.47 Ac |
| Brown Sugar        | 93.25 ± 13.84 Aa | 85.36 ± 0.54 Ab | 168.82 ± 2.94 Bb | 44.16 ± 0.96 Bb | 60.83 ± 5.81 Bb | 60.83 ± 2.47 Bb | 60.83 ± 2.92 Ac |

| Antioxidant capacity – DPPH |
| (EC₅₀ – g f.w./g DPPH) |
| White Crystal Sugar | 39.01 ± 1.60 Ae | 602.73 ± 1.60 Ae | 2885.34 ± 4.66 Ad | 3334.23 ± 4.66 Ac | 3186.34 ± 4.66 Aa | 3227.35 ± 0.96 Ac | 3241.64 ± 2.34 Ac |
| White Refined Sugar | 38.26 ± 1.08 Ae | 550.41 ± 1.08 Ae | 2327.35 ± 0.96 Ac | 3106.90 ± 0.96 Ac | 3106.90 ± 0.96 Ac | 3106.90 ± 0.96 Ac | 3106.90 ± 0.96 Ac |
| Demerara Sugar     | 48.42 ± 2.63 Ac | 622.04 ± 2.63 Ac | 3175.38 ± 2.63 Ac | 3241.69 ± 2.63 Ac | 3175.38 ± 2.63 Ac | 3241.69 ± 2.63 Ac | 3175.38 ± 2.63 Ac |
| Brown Sugar        | 40.45 ± 0.90 Ae | 625.07 ± 0.90 Ae | 2969.36 ± 0.90 Ae | 3554.06 ± 0.90 Ae | 3554.06 ± 0.90 Ae | 3554.06 ± 0.90 Ae | 3554.06 ± 0.90 Ae |

| Antioxidant capacity – β-carotene |
| (% protection) |
| White Crystal Sugar | 16.08 ± 0.89 Ba | 5.79 ± 2.05 Cc | 10.22 ± 2.62 Bb | 15.00 ± 2.16 Ba | 2.34 ± 0.77 Ab | 2.34 ± 0.77 Ab |
| White Refined Sugar | 18.68 ± 0.34 Ba | 8.60 ± 3.55 Cc | 18.16 ± 2.27 Ab | 12.75 ± 3.04 Ab | 4.53 ± 1.35 Ac | 4.53 ± 1.35 Ac |
| Demerara Sugar     | 19.07 ± 3.31 Bb | 19.42 ± 5.55 Bb | 13.79 ± 2.81 Ab | 12.52 ± 5.18 Ab | 26.44 ± 5.18 Ab | 26.44 ± 5.18 Ab |
| Brown Sugar        | 25.53 ± 2.37 Ab | 35.24 ± 0.13 Aa | 14.82 ± 3.68 Ac | 9.42 ± 3.20 Ac | 24.72 ± 4.48 Ab | 24.72 ± 4.48 Ab |

Source: Flávio Santos de Assis. Means ± standard deviation followed by the same capital letter in the column and lowercase in the row do not differ by Scott-Knott test at 5% probability, n=4.

The coloring of the jaboticaba jelly is indicative of the amount of anthocyanins present in the product, and the higher the anthocyanin content, the darker the jelly, possibly due to less pigment degradation (Freitas-Sá et al., 2018). Therefore, a reduction in the anthocyanin content during the 120 days of storage was found in all jaboticaba jelly formulations (Table 3), being equal (p> 0.05) at the end of the period (T120).

Certain factors, such as pH, presence of light, oxygen concentration, presence of copigments, existence of metal ions and enzymes, storage time, and high temperatures may affect the anthocyanin content of jellies (Martynenko & Chen, 2016; Tobal & Rodrigues, 2019). In short, it can be inferred that sugars did not provide stability to the jellies in relation to the anthocyanin content, since there was degradation of this substance in all jaboticaba jelly formulations.
formulations during the 120 days of storage. However, jellies with brown sugar and demerara obtained higher anthocyanin levels at the beginning of storage (p> 0.05), possibly due to the composition of these sugars. To obtain brown sugar, the clarification process is not carried out so that the jelly keeps the characteristics of the sugarcane juice and the substances responsible for the color (chlorophyll, saccharin, anthocyanins, and polyphenols) (Asikin et al., 2014). Demerara sugar, on the other hand, presents relatively high nutritional values, similar to brown sugar, since, during its production, chemical additives are not used. It also undergoes a slight refinement and a layer of molasses surrounds the crystals (Manohar et al., 2014). Therefore, it can be inferred that the components present in brown sugar, such as magnesium, iron, phosphorus, sodium, and potassium, may have protected anthocyanins from further degradation, such as that which occurs in jellies with crystal and refined sugars.

Vitamin C values were higher at the beginning of storage in jellies that used crystal and refined sugar (p> 0.05) (Table 3), compared with those that were prepared with demerara and brown sugars. However, after 120 days, the ascorbic acid levels were the same for all jellies (p> 0.05). In addition, vitamin C levels decreased over 120 days of storage in all jaboticaba jelly samples. A similar result was found by Tobal & Rodrigues (2019), who observed a reduction in the vitamin C content of conventional pitanga jelly over 140 days of storage. According to Martinsen et al. (2020), a long storage period helps the degradation of vitamin C, since this vitamin is degraded at high temperatures and in the presence of light. These same authors report that for these characteristics, vitamin C is used as an indicator of nutrient retention in products after processing. Thus, after analyzing the results of this study, we expect that bioactive compound degradation will occur in all jaboticaba jelly formulations over the storage time. According to the vitamin C recommended daily intake (RDA), healthy adults should consume 75 mg/day for women and 90 mg/day for men (Krinsky, 2000). Thus, it is observed that the consumption of 100 g of different jaboticaba jelly formulations will not provide the recommended daily vitamin C intake for the groups mentioned. However, according to the recommended consumption, when ingesting 20 g of jaboticaba jelly, the consumer will be provided with 3.4% of the average daily intake, according to the recommendation for healthy adults. In addition, according to the classification of Ramful et al. (2011), in which the ascorbic acid content is classified as: 1) low: less than 30 mg/100 g, 2) medium: from 30 to 50 mg/100 g, and 3) high: greater than 50 mg/100 g, jellies with crystal and refined sugars can be classified as
having medium vitamin C levels, and jellies prepared with demerara and brown sugars have low vitamin C levels at the beginning of storage. However, during the storage period, due to degradation, all jellies presented low final vitamin C contents. It was found in this study that the different jaboticaba jelly formulations had a low vitamin C content compared to low-calorie orange jellies, which was investigated in study by Santos et al. (2020). These investigators found an average vitamin C value of 97.85 mg/100 g of ascorbic acid at the end of the storage period.

With regard to the total phenolic content, the high content present in the jelly prepared with brown sugar, mainly that observed at time T0, is possibly due to the presence of these compounds in brown sugar, since this sugar is considered raw and preserves sugar cane characteristics, such as the presence of phenolic compounds (Jaffé, 2012; Asikin et al., 2014). According to Vasco et al. (2008), jaboticaba jellies have a medium content of total phenolics (1 to 5 mg GAE/g). At the end of storage, there was a difference between these jellies (p ≤ 0.05) and those made with refined and demerara sugars, which obtained higher values for these compounds (p ≤ 0.05). In addition, the degradation of these compounds occurred for all jelly formulations during 120 days of storage. Tobal & Rodrigues (2019) also observed a reduction in total phenolics content during storage in pitanga jelly made with sucrose. This degradation may be due to the oxidation of phenolics and polymerization reactions, which reduce free hydroxyl groups (Laorko et al., 2013).

Regarding antioxidant capacity, according to the literature, several methods must be used to measure antioxidants and their by-products in foods of plant origin, since several bioactive compounds and antioxidant mechanisms occur in plants (Sánchez-Moreno, 2002; Sousa et al., 2011). Therefore, each method follows a different principle and uses different free radicals and/or patterns (Sousa et al., 2011).

Using the ABTS method, the jelly prepared with demerara sugar presented a higher antioxidant capacity at the beginning of the storage, followed by jellies prepared with refined and brown sugars. However, at the end of 120 days, there was no statistical difference (p > 0.05) between jaboticaba jellies. In addition, there was a reduction in antioxidant capacity in all jellies during the storage period.

Regarding the results of the DPPH method, which consists of the inhibition of the DPPH radical (2,2-diphenyl-1-picryl-hydrazil) by antioxidants, no difference (p >0.05) was found in antioxidant content between jellies at the beginning of storage. However, the antioxidant capacity
reduced during storage, where, at the end of the 120 days, the jelly prepared with refined sugar showed greater (p ≤0.05) antioxidant capacity. The results of this analysis are expressed as EC\textsubscript{50} values, which indicates the sample concentration capable of removing 50% of the DPPH free radical (Santos et al., 2020). In addition, the lower the EC\textsubscript{50} value, the greater the antioxidant activity (Sousa et al., 2011).

Using the lipid peroxidation inhibition methodology with the β-carotene/linoleic acid, the jelly produced with brown sugar had a higher (p ≤0.05) percentage of protection at the beginning of storage. At the end of storage, jellies prepared with brown and demerara sugars had higher percentages of protection than those made with white sugar. During storage, there was a reduction in the values of jellies prepared with crystal and refined sugars. At the end of 120 days, jellies prepared with demerara and brown sugars had higher percentages. Thus, it can be inferred that dark sugars were responsible for preserving the antioxidant capacity of the jaboticaba extract, as assessed by this method. In contrast, white sugars reduced the percentage of jaboticaba jelly protection during storage.

In view of the results found by the methods used to determine the antioxidant activity in different jaboticaba jelly formulations, the chemical alterations and degradations caused by the antioxidants as well as the formation of new antioxidants that occurred during storage, as an effect of the Maillard reaction between ingredients, causes changes in the antioxidant activity of the samples during storage (Tobal & Rodrigues, 2019). In addition, the characteristics present in some sugars led to changes in the jellies.

Pearson's correlation coefficients between bioactive compounds and the antioxidant capacity of jaboticaba jellies are shown in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Anthocyanins</th>
<th>Vitamin C</th>
<th>Total phenolics</th>
<th>ABTS</th>
<th>DPPH</th>
<th>β-carotene (% protection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthocyanins</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td>-0.60</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total phenolics</td>
<td>0.99***</td>
<td>-0.67</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABTS</td>
<td>0.95*</td>
<td>-0.82</td>
<td>0.97*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPPH</td>
<td>-0.63</td>
<td>0.53</td>
<td>-0.64</td>
<td>-0.61</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>β-carotene (% protection)</td>
<td>0.89</td>
<td>-0.90</td>
<td>0.92</td>
<td>0.98*</td>
<td>-0.66</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Paloma Cristina dos Santos. *p < 0.05, **p < 0.01
Anthocyanin content was positively correlated with the total phenolic content (0.99, p <0.01) and antioxidant capacity by the ABTS method (0.95, p <0.05) (Table 4). The total phenolic content positively correlated with the antioxidant capacity measured by the ABTS method (0.97, p <0.05). In addition, a significant positive correlation (0.98, p <0.05) was observed between antioxidant capacities determined using ABTS and β-carotene/linoleic acid methods.

In jaboticabas, anthocyanins are the most abundant phenolic compounds (Zhang et al., 2018). Therefore, the values obtained for the total phenolics contents can be attributed to the anthocyanin content, which is also responsible for the antioxidant capacity of the jelly.

Thus, it can be inferred that, in general, jaboticaba jellies made with demerara sugar had higher levels of bioactive compounds and antioxidant capacity during storage.

4 CONCLUSIONS

The sugars used in the preparation of jaboticaba jellies and the storage durations influenced the microbiological characteristics, color, bioactive compounds, and antioxidant capacity of the jaboticaba jellies. Despite the growth of molds and yeasts, their jelly values remained within the standards allowed by Brazilian legislation. During storage, all jellies under study darkened, and those made with white sugar (crystal and refined) were more vivid. At the end of the 120 days, jellies prepared with crystal and brown sugars remained red, while those made with refined and demerara sugars turned orange.

There was degradation of the bioactive compounds studied and reduction in antioxidant capacity, as verified by the ABTS and DPPH methods, in all jaboticaba jelly formulations at the end of storage. The content of anthocyanins, vitamin C, and antioxidants determined by the ABTS method showed no statistical difference between formulations at the end of storage. Jellies made with brown sugar and demerara had higher contents of total phenolics, anthocyanins, and antioxidants during storage based on the results of the ABTS and β-carotene/linoleic acid methods. Positive correlations were observed, and the content of monomeric anthocyanins, content of phenolic compounds, and antioxidant capacity determined by the ABTS method correlated best. Thus, demerara sugar, even though it does not provide brightly colored jellies, is the most useful for the production of jaboticaba jellies, due to the presence of bioactive compounds and antioxidant capacity.
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