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Degradation kinetics and stability of bioactive compounds, antioxidant capacity, and color parameters of sugar-free jaboticaba jellies subjected to different preservation methods

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Abstract

Jaboticaba (*Myrciaria cauliflora*), a fruit native to Brazil, is known for its high anthocyanin and phenolic compound contents. Making jellies without added sugars is a promising alternative for utilizing this fruit, but maintaining the stability of its bioactive compounds and its characteristic color are significant challenges. Therefore, this study evaluated the effects of different preservation methods (gamma irradiation and potassium sorbate addition) on bioactive compound stability, antioxidant capacity, and color parameters of jaboticaba jellies without added sugar during 114 days of storage. The experiment was conducted using a completely randomized design (2 × 7) with three replicates. The results showed that the preservation method and storage time significantly influenced the analyzed parameters. Gamma irradiation promoted greater preservation of vitamin C, total phenolic compounds, and antioxidant capacity, whereas potassium sorbate addition resulted in greater degradation of these constituents. The degradation kinetics of anthocyanins and phenolics followed a first-order model, with a lower degradation rate in the irradiated jelly. Color changes (L*, a*, b*, ΔE*) reflected progressive loss of pigments, which was more pronounced in the irradiated formulation. Overall, we conclude that gamma irradiation is a promising alternative for preserving dietary jellies and ensuring greater nutritional stability during storage.

Keywords: *Myrciaria cauliflora*; sugar-free product; food preservation; gamma irradiation; potassium sorbate.

1 INTRODUCTION

Jaboticaba (*Myrciaria cauliflora*), a fruit native to Brazil, is characterized by its sweet and sour taste, high nutritional value, and high phenolic content (Batista et al., 2025; Pinto et al., 2021). It is one of the main sources of anthocyanins in Brazil (Leite-Legatti et al., 2012). It is a large shrubby tree capable of producing thousands of globose fruits per harvest, with reddish, almost black skin, whitish, mucilaginous pulp, and one to four seeds (Pinto et al., 2024). Recently, jaboticaba has been classified as a superfruit because of its potential health-promoting effects, including reducing postprandial glucose and insulin levels as well as increasing antioxidant capacity in humans (Marsiglia et al., 2023). In addition to tannins, jaboticaba fruits contain high levels of anthocyanins, such as cyanidin-3-glucoside, peonidin-3-glucoside, and aglycone derivatives (Einbond et al., 2004). According to Teixeira et al. (2011), crude methanolic extracts of jaboticaba demonstrated strong antiradical activity using the DPPH method (EC_{50} = 35 μg mL^{-1}). However, because it is highly perishable, jaboticaba needs to be transformed into products such as jellies, jams, liqueurs, and juices for its full utilization (Santos et al., 2024).

The fruit jelly market has shown continuous growth owing to its sensory acceptability, high added value, and nutritional quality (Lima et al., 2019). However, sugar-free versions are in growing demand, driven by the increasing incidence of chronic noncommunicable diseases such as diabetes and obesity (Horne et al., 2019; Lima et al., 2023). In this context, sugar-free jellies provide a promising alternative to meet the needs of consumers seeking healthier products without compromising on flavor and quality (Lima et al., 2023).

The absence of sugar in jelly formulations, although beneficial from a nutritional perspective, compromises the microbiological stability of the product because sucrose exerts a preservative effect by reducing water activity (Plotnikova

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et al., 2022). Furthermore, sugar contributes to the body and texture of the product; therefore, its removal can result in jellies with inadequate consistency (Farias et al., 2023). To overcome this problem, bulking agents such as galactooligosaccharides (GOS) have been used to provide better texture along with functional benefits, as they are considered prebiotics (Lima et al., 2024; Souza et al., 2022). Simultaneously, chemical additives such as potassium sorbate have been widely used for preservation purposes, as they are effective against yeasts, molds, and some bacteria (Yardimci et al., 2022). However, they have disadvantages, such as a possible impact on flavor, loss of effectiveness at high pH, and growing rejection by consumers seeking foods with lower artificial additive content (Davidson et al., 2013; Dehghan et al., 2018; Guzik et al., 2022). Therefore, further studies are required to evaluate safer and more effective alternatives for preserving sugar-free jellies.

Among these, food irradiation, particularly gamma irradiation, has shown promise (Pi et al., 2022). The process involves application of ionizing radiation at controlled doses, which can inactivate spoilage-causing and pathogenic microorganisms without compromising the sensory and nutritional quality of foods (Santos et al., 2024). Furthermore, this technology is recognized as safe by several international organizations, including the FAO, IAEA, and WHO, and is currently applied to fruits, vegetables, juices, spices, and minimally processed products (Arefin et al., 2025). Therefore, its use as a preservation strategy for dietary jellies represents a viable alternative to chemical preservatives, thereby addressing the demand for healthier foods with greater consumer acceptance.

Therefore, the present study aimed to evaluate the effects of different preservation methods (addition of potassium sorbate and gamma irradiation) on the stability of bioactive compounds, antioxidant capacity, and color parameters of sugar-free jaboticaba jellies during storage.

1.1 Relevance of the work

This study is important because it investigates the impact of different preservation methods on the stability of bioactive compounds, antioxidant capacity, and color of sugar-free jabuticaba jams, a product with great functional and commercial potential. The comparative evaluation between gamma irradiation and potassium sorbate contributes to the advancement of knowledge about clean and effective technologies for preserving dietary foods. The results demonstrate that irradiation better maintains the nutritional and antioxidant quality of the product, providing a scientific basis for the use of this technique in preserving foods without added sugars.

2 MATERIALS AND METHODS

2.1 Ingredients

Jaboticabas obtained in the Ouro Preto-MG region, galactooligosaccharides (Nutramax®), sweeteners (Acesulfame-k - Nutramax® and Sucralose - Nutramax®), κ-carrageenan (GastronomyLab®), and potassium sorbate (Dinâmica®) were used.

2.2 Preparation of sugar-free jaboticaba jellies

The jelly production procedure was adapted from Pinto et al. (2021), with some modifications. The jaboticabas were selected, washed, and sanitized in a sodium hypochlorite solution (2.5%) for 15 min, and subsequently rinsed in running water to remove any residual solution. They were then blanched for 5 minutes at a 1:0.5 ratio (jaboticaba:water) and blended in an industrial blender (Tron®, Tron Master 2 L, Catanduva, SP, Brazil) for three 5-second cycles. The resulting jaboticaba pulp was filtered through a fine mesh sieve (~20 mesh) to separate the solid residue from the final aqueous extract.

In total, two formulations were developed, with and without potassium sorbate. The aqueous extract (84.33%) and galactooligosaccharide (15%) mixture was heated in an open stainless steel pan to 70 °C. Then, κ-carrageenan (0.65%) previously homogenized under intense stirring in water at 80 °C was added. The mixture was cooked until it reached a soluble solid content of 45 °Brix. Finally, sucralose (0.0065%) and acesulfame-K (0.01875%) were added after diluting with water at room temperature in a 1:1 ratio to avoid thermal degradation (Pereira et al., 2013). Potassium sorbate (0.05%) was added at the end of the cooking process to prepare the preservative-containing formulation. The jellies were hot-filled into glass jars with metal lids, which were previously sterilized by boiling (15 min), cooled in an inverted position, and stored in temperature-controlled chambers (25 °C) in a conventional position. All levels were established based on preliminary tests. After bottling, the jelly formulation without potassium sorbate was subjected to gamma irradiation (2.0 kGy) at the Gamma Irradiation Laboratory (LIG) of the Center for Nuclear Technology Development (CDTN/CNEN). The 2.0 kGy dose was selected based on the study by Mesquita et al. (2020), reporting a significant reduction in fungi and yeast during the storage of grape juice at room temperature, combined with reduced degradation of bioactive compounds and antioxidant capacity.

2.3 Instrumental color evaluation

The color of the jellies was determined as described previously (Patras et al., 2011) by L* [lightness (L = 100; white and L = 0; black)], a* [green (−) to red (+) chromaticity], and b* [blue (−) to yellow (+) chromaticity] using a Konica Minolta CR-400 color meter, working at D65 (daylight) and with CIELab standards. The colorimeter was calibrated before analysis using a Konica Minolta white calibration plate.

Furthermore, the total color difference (ΔE*) was calculated using Equation 1:

$$\Delta E^* = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (1)$$

Where:

L0, a0, and b0: the respective values of the jellies at Day 0.

2.4 Determination of ascorbic acid (vitamin C)

The standard AOAC methodology (1984), modified by Benassi and Antunes (1998), was used to determine ascorbic acid content. The samples were diluted in 100 mL of 2% oxalic acid solution, and a 25 mL aliquot was titrated with 0.025% 2,6-dichlorophenolindophenol (DCFI) solution until a pink color was obtained; the solution was previously standardized with L-ascorbic acid solution.

2.5 Total monomeric anthocyanin content

Total monomeric anthocyanin content (TMAC) was estimated using the pH differential method (Waterhouse, 2002). Briefly, each jelly was diluted with pH 1.0 and pH 4.5 buffers to attain the same dilution. Absorbance was measured at 510 nm and 700 nm in both pH 1.0 and pH 4.5 buffers. TMAC (expressed in terms of cyanidin-3-glucoside) was then calculated using Equations 2 and 3:

$$A = (A_{510} - A_{700})_{pH1,0} - (A_{510} - A_{700})_{pH4,5} \quad (2)$$

$$TMAC = (A \; x \; MW \; x \; DF \; x \; Ve \; x \; 1000) \; / \; (\varepsilon \; x \; 1 \; x \; M) \quad (3)$$

Where:

MW: the molecular weight of cyanidin-3-glucoside (449 g mol^{-1});

DF: the dilution factor;

Ve: the extract volume;

ε: the molar extinction coefficient of cyanidin-3-glucoside (29,600);

M: the mass of the jellies.

The results were expressed as mg cyanidin-3-glucoside equivalents/100 g.

2.6 Obtaining extracts of samples for analyzing phenolic compounds and antioxidant capacity

The extraction procedure was adapted from Larrauri et al. (1997). The sample (10 g) was weighed, and 40 mL of a methanol/water solution (50:50 v/v) was added. This solution was stirred (200 rpm) at room temperature for 60 min and allowed to stand in a cool (8 °C) environment for 30 min. The supernatant was then filtered, recovered, and transferred to a 100 mL flask. An acetone/water (40 mL; 70:30 v/v) mixture was then added to the residue while stirring (200 rpm) at room temperature for 60 min, and the mixture was allowed to stand in a cool (8 °C) environment for 30 min. The supernatant was then transferred to a volumetric flask containing the first supernatant, and the volume was made up to 100 mL with distilled water. This procedure was performed under light, and the extract was stored at –18 °C.

2.6.1 Total phenolic compounds

A methodology based on the Medina (2011) method was used to determine the total phenolic compounds in the jaboticaba jellies. The extract (4.0 mL) was pipetted and transferred to test tubes containing .4 mL of 0.01% (v/v) Fast Blue reagent and .4 mL of 5% (w/v) sodium hydroxide solution. The contents of the tubes were homogenized and held for 120 min under light; the absorbance was then determined at 420 nm. Absolute ethanol was used as the blank. The total phenolic content was determined by interpolating the sample absorbance against the calibration curve constructed using gallic acid standards (40, 80, 120, 160, 240, 320, and 400 μg mL^{-1}). The results were expressed as milligrams of gallic acid equivalent (GAE)/g.

2.6.2 Antioxidant capacity

Antioxidant capacity was determined using the ABTS, DPPH, and FRAP methods.

The method described by Re et al. (1999) was used for the ABTS (2,2′-azino-bis-(3 ethylbenzenothiazoline-6-sulfonic acid)) assay, with minor modifications. The ABTS radical cation ($ABTS^{+}$) was generated by the reaction of 5 mL of aqueous ABTS solution (7 mM) with 88 μL of 140 mM (2.45 mM final concentration) potassium persulfate. The mixture was kept in the dark for 16 h before use and then diluted with ethanol to obtain an absorbance of 0.7 ± 0.05 units at 734 nm using a spectrophotometer. The jelly (30 μL), or a reference substance (Trolox—6-hydroxy-2,5,7,8-tetramethyl chroman-2-carboxylic acid), was reacted with 3 mL of the resulting blue–green ABTS radical solution in the dark. The decrease in absorbance at 734 nm was measured after 6 min. Ethanolic solutions of known Trolox concentrations were used for calibration. The results are expressed as moles of Trolox equivalents (TEs) per gram of jelly (μmol of TEs/g).

DPPH free radical scavenging capacity was estimated as reported by Brand-Williams et al. (1995). The DPPH (2,2-diphenyl-1-picrylhydrazyl) solution (600 μM) was diluted with ethanol to obtain an absorbance of .7 ± .02 units at 517 nm. The jelly extracts (.1 mL) were allowed to react with 3.9 mL of the DPPH radical solution for 30 min in the dark, and the decrease in the absorbance of the resulting solution at 517 nm was monitored. The results are expressed as EC_{50} (g of jelly per gram of DPPH).

FRAP is based on the reduction of ferric 2,4,6-tris(2-pyridyl)-1,3,5-triazine [Fe(III)-TPTZ] to a ferrous complex at low pH, followed by spectrophotometric analysis (Benzie & Strain, 1996). Briefly, the reagent was prepared by mixing 10 mmol 2,4,6-Tris(2-pyridyl)-s-triazine (TPTZ)/L reagent with 20 mmol/L ferric chloride in acetate buffer (pH 3.6). Quantitative analyses were performed using ferrous sulfate (20 mM) as the reference standard. Exactly .09 mL of jelly samples was mixed with .27 mL of distilled water and 2.7 mL of FRAP reagent. After 30 min, the absorbance was measured at 595 nm. The results were calculated and expressed as micromoles (μM) ferrous sulfate per gram.

2.7 Experimental design and analysis of results

The experiment was conducted using a completely randomized design (CRD) in a 2 × 7 full factorial arrangement with three

replicates. The factors evaluated were jelly type (irradiated and with added potassium sorbate) and storage time (0, 15, 30, 51, 72, 93, and 114 days).

The results obtained for bioactive compounds, antioxidant capacity, and color parameters were subjected to univariate analysis of variance (ANOVA), and the means were compared using Tukey's test at a 5% significance level ($p \leq 0.05$), using Sisvar software (Ferreira, 2014).

The degradation of anthocyanins and phenolic compounds in unsweetened jaboticaba jellies subjected to different preservation methods was calculated using the standard equation for zero-order and first-order reactions, and the degradation rate constants were determined by fitting Equations 4 and 5 to the experimental data.

$$C = C_0 + k_0 t \quad (4)$$

$$C = C_0 e^{k_1 t} \quad (5)$$

Where:

C: the studied parameter (anthocyanins and phenolic compounds) at any reaction time;

C_0: the initial value of the sample;

k_0 and k_1: the rate constants.

The data fit was considered significant at the 95% probability level. ANOVA was performed to determine significant differences ($p < .05$) during storage.

Pearson's correlation coefficient was used to correlate the obtained parameters. Data analysis was performed using SPSS software (version 27.0) (IBM SPSS Statistics, SPSS Inc., Chicago, IL, USA) for Windows.

3 RESULTS AND DISCUSSION

3.1 Effect of storage time and method on bioactive compound levels, antioxidant capacity, and color parameters in prepared jellies

Storage time and preservation method significantly affected vitamin C levels (Table 1). At the beginning of the storage period (Day 0), the jelly with added potassium sorbate had the highest value ($p < .05$); however, at the end of the storage period (Day 114), the irradiated jelly had a significantly higher value ($p < .05$). Furthermore, an increase in vitamin C levels was observed in the irradiated jelly throughout storage. According to Mesquita et al. (2020), the sugars present in the samples can be used as substrates in vitamin C biosynthesis. Thus, gamma irradiation may have promoted the release of sugars from the food matrix, contributing to the observed increase in vitamin C levels. Furthermore, this increase may be related to the partial conversion of ascorbic acid (AA) to dehydroascorbic acid (DHA), promoted by ionizing radiation, followed by the subsequent reduction of DHA to AA during titrimetric analysis, which quantifies total vitamin C (Kilcast, 1994). This phenomenon has already been described for irradiated products, wherein radiation alters the balance between the active and oxidized forms of vitamin C without necessarily causing its complete degradation (Dionísio et al., 2009). The vitamin C content of the jelly with potassium sorbate was significantly reduced during storage, with a loss of 57.43%. This decrease may be associated with the action of oxidative enzymes such as AA oxidase (ascorbinase) and peroxidase, which promote AA degradation (Jenjob et al., 2017). Furthermore, AA is highly unstable under adverse environmental conditions and susceptible to oxidation in the presence of oxygen, light, trace metals, and high temperatures (Yin et al., 2022). Although potassium sorbate acts as an antimicrobial preservative, its application does not confer antioxidant protection to the matrix (Kitano et al., 2002). The absence of antioxidant compounds may have favored redox reactions as well as non-enzymatic browning processes, such as

Table 1. Changes in the values of bioactive compounds in sugar-free jaboticaba jellies subjected to different preservation methods.

Treatments		Vitamin C (mg/100 g)	Total anthocyanin (mg of cyanidin 3-glucoside equivalent/100 g)	Total phenolics (mg GAEs/100 g)
Irradiated	Day 0	49.52 ± 0.00^{bG}	29.64 ± 0.20^{bA}	0.99 ± 0.01^{aB}
	Day 15	150.83 ± 0.00^{aA}	15.30 ± 0.39^{bB}	0.88 ± 0.01^{aBC}
	Day 30	75.73 ± 0.00^{aB}	11.69 ± 0.29^{bC}	2.23 ± 0.01^{aA}
	Day 51	71.82 ± 0.00^{aC}	10.61 ± 0.47^{bD}	0.75 ± 0.08^{bCD}
	Day 72	54.70 ± 0.00^{aF}	4.55 ± 0.57^{bF}	0.95 ± 0.00^{aB}
	Day 93	62.48 ± 0.00^{aD}	6.81 ± 0.41^{aE}	1.00 ± 0.02^{aB}
	Day 114	57.15 ± 0.00^{aE}	4.63 ± 0.16^{aF}	0.69 ± 0.01^{aD}
Potassium sorbate	Day 0	67.12 ± 0.00^{aB}	41.30 ± 0.14^{aA}	0.84 ± 0.02^{bB}
	Day 15	47.13 ± 0.00^{bD}	28.62 ± 0.75^{aB}	0.84 ± 0.02^{aB}
	Day 30	75.73 ± 0.00^{aA}	17.66 ± 0.59^{aC}	2.02 ± 0.04^{bA}
	Day 51	35.91 ± 0.00^{bF}	14.10 ± 0.82^{aD}	0.89 ± 0.02^{aB}
	Day 72	54.70 ± 0.00^{aC}	7.94 ± 0.75^{aE}	0.94 ± 0.02^{aB}
	Day 93	41.65 ± 0.00^{bE}	6.46 ± 0.61^{aF}	0.67 ± 0.01^{aC}
	Day 114	28.57 ± 0.00^{bG}	4.85 ± 0.46^{aG}	0.56 ± 0.00^{bC}

Values with different superscript lowercase letters indicate a statistically significant difference between treatments at the same storage time using Tukey's test ($p \leq 005$).
Values with different superscript uppercase letters indicate a statistically significant difference between storage times within the same treatment using Tukey's test ($p \leq .05$).

the Maillard reaction, wherein AA acts as a reagent, resulting in its degradation (Yu et al., 2012). Furthermore, the acidic pH of jellies and occasional exposure to light during storage may have intensified these losses, as previously reported in studies on irradiated or thermally processed foods (Abe-Matsumoto et al., 2020; Dionísio et al., 2009).

Regarding anthocyanin levels, a higher value was observed in the jelly treated with potassium sorbate at the beginning of storage (Day 0). However, at the end of the study period (Day 114), both formulations presented similar values. Further, anthocyanin degradation occurred in both the irradiated jelly and the jelly with potassium sorbate during storage, possibly because of the low sugar concentration in the formulations. According to Shinwari and Rao (2018), the sugars present in jellies contribute to the stabilization of anthocyanins through the absorption of flavylium cations. These authors also stated that sugars reduce water activity and prevent the nucleophilic attack of the water molecule on the flavylium cation at the C-2 position, preventing the formation of a colorless carbinol base. However, at low concentrations, sugar degradation products (such as furfurals) from reactions, such as the Maillard reaction, can accelerate anthocyanin degradation. Scibisz and Mitek (2009) reported that blueberry jellies with high soluble solid content (60%) had significantly higher ($p < .05$) total monomeric anthocyanin (TMA) levels, between 11% and 14% higher than in jellies with low soluble solid content (38%). For the latter, the lower water activity and partial oxygen barrier conferred by the sugars were identified as possible reasons for the lower levels. Furthermore, jellies with 20% soluble solids, containing oligofructose and free of sucrose, showed the lowest AMT concentration, which was attributed to the thermal hydrolysis of oligofructose to fructose, resulting in a deleterious effect on anthocyanins. Although galactooligosaccharides (GOS) and oligofructose are distinct compounds, they are both oligosaccharides susceptible to thermal hydrolysis to monosaccharides (such as fructose or galactose), which can accelerate anthocyanin degradation (Moura et al., 2015).

Considering that the jellies were prepared without the addition of sucrose and with GOS in the present study, the low soluble solid content associated with the presence of GOS may have contributed to the greater degradation of anthocyanins during storage. The jellies were stored for 114 days, a period sufficient to favor the progressive degradation of anthocyanins, as already observed in products with low sugar concentration and absence of protective polymers (Patras et al., 2010). Furthermore, although the formulation contained carrageenan gum, this anionic polysaccharide did not act directly as an anthocyanin stabilizer (Navikaite et al., 2016). Depending on the system conditions, its presence can influence the stability of these compounds in a neutral or even slightly unfavorable way (Xue et al., 2024), unlike other polysaccharides, such as gum arabic, starch, or β-glucans, which form protective complexes with anthocyanins (Dong et al., 2023). Therefore, both storage time and the absence of specific stabilizing polymers may have contributed to the observed AMT loss in the samples over time.

Total phenolic compound levels varied significantly among the studied samples (Table 1). At the end of the storage period, the gamma-irradiated jelly had a significantly higher value than that observed for the sample containing potassium sorbate ($p < .05$), although both underwent degradation over time. In the irradiated sample, the initial increase in total phenolics may be associated with the breakdown of glycosidic bonds and the degradation of high-molecular-weight phenolic polymers into lower-mass compounds, which are more easily detectable by the analytical methods used (Harrison & Were, 2007; Mesquita et al., 2020). Additionally, gamma irradiation can induce the activity of phenylalanine ammonia lyase (PAL), a key enzyme in the phenylpropanoid pathway, resulting in the biosynthesis of new phenolic compounds in response to radiation-induced oxidative stress, a defense mechanism widely reported in plant tissues and plant-derived products (Oliveira et al., 2016). This effect characterizes irradiation as an abiotic stressor capable of stimulating secondary metabolism and consequently increasing the production of antioxidant metabolites.

After 114 days of storage, a reduction of 30.3 and 33.3% in the total phenolic content was observed in the irradiated and potassium sorbate–treated jellies, respectively. The greater preservation observed in irradiated samples may be related to the fact that, in addition to controlling spoilage microbiota, irradiation reduces the oxidative enzyme load by partially inactivating enzymes, such as polyphenol oxidase (PPO) and peroxidase (POD), which are responsible for the oxidative degradation of phenolics (Beaulieu et al., 1999; Fan, 2005). In contrast, potassium sorbate, although an effective antimicrobial preservative against yeasts and molds, has no antioxidant effect or any ability to induce physiological responses that favor the synthesis or preservation of phenolic compounds (Dehghan et al., 2018; Piper & Piper, 2017). Its action is restricted to inhibiting microbial growth, and it does not act on metabolic pathways or inactivate degradative enzymes (Kimani et al., 2023). The antioxidant capacity of the prepared jellies was determined through in vitro tests, including the neutralization of DPPH (Brand-Williams et al., 1995) and ABTS (Re et al., 1999) free radicals, and evaluation of ferric reducing power (FRAP), based on the reduction of Fe^{3+} ions to Fe^{2+} (Benzie & Strain, 1996) (Table 2).

The antioxidant capacity of the jellies determined by the ABTS method decreased during storage (Table 2), probably because of the degradation of phenolic compounds and other water-soluble antioxidants such as anthocyanins and AA, resulting from the oxidation and polymerization reactions induced by factors such as the presence of oxygen, pH variations, and temperature (Giovanelli & Buratti, 2009). At the end of 114 days, the jellies subjected to irradiation showed greater antioxidant capacity than that of the formulation with potassium sorbate ($p \leq .05$). This result may be related to the fact that irradiation at adequate doses can inactivate oxidative enzymes, such as polyphenol oxidase and peroxidase, thus preserving sensitive bioactive compounds (Alothman et al., 2009; Fan, 2005). In contrast, potassium sorbate acts exclusively as an antimicrobial preservative and does not provide protection against oxidative reactions that lead to the loss of antioxidants (Harrison & Were, 2007). Furthermore, the ABTS method, which is more sensitive to the detection of hydrophilic compounds such as simple phenolics and vitamin C, tends to more clearly demonstrate the reduction of these compounds over time (Re et al., 1999).

The antioxidant capacity of the jellies was determined using the DPPH stable radical method and expressed as the effective concentration (EC_{50}), which corresponds to the amount of sample required to inhibit 50% of radical activity (Chen et al., 2013). The samples subjected to irradiation showed no significant variation in EC_{50} values during the 114 days of storage, indicating the stability of antioxidant activity over time, a result similar to that reported for irradiated vegetable products (Fan & Sokorai, 2008; Marathe et al., 2017) (Table 2). In contrast, the formulation containing potassium sorbate showed a significant increase in EC_{50} values during the final storage period, indicating a reduction in antioxidant capacity, possibly owing to the degradation of phenolic compounds and other natural antioxidants during storage (Tavares et al., 2020). Furthermore, at the end of the experimental period, the irradiated jelly showed lower EC_{50} values than those in the sample with potassium sorbate, demonstrating greater efficiency in neutralizing DPPH radicals. These findings suggest that irradiation can act as a preservation technology capable of preserving the bioactive compounds responsible for antioxidant activity in fruit products, even after long storage periods (Alothman et al., 2009; Ito et al., 2019).

Regarding the antioxidant capacity assessed using the FRAP method, no significant differences were observed between the jellies, nor were there any changes in antioxidant activity over the storage period of the analyzed samples ($p > .05$). The absence of this variation may indicate that the antioxidant compounds present in the jellies have greater affinity or efficacy in neutralizing free radicals (assessed by the ABTS and DPPH methods) than in reducing metal ions, as assessed by the FRAP (Prior et al., 2005).

The color values (L*, a*, and b*) of the jellies are presented in Table 3. Color is one of the important parameters that attracts consumers. Its evaluation is used to determine the effects of

Table 2. Changes in the antioxidant capacity of sugar–free jaboticaba jellies subjected to different preservation methods.

Treatments		Antioxidant capacity – ABTS (μmol/g)	Antioxidant capacity – DPPH (EC_{50} – g/g DPPH)	Antioxidant capacity – FRAP (μM ferrous sulfate/g)
Irradiated	Day 0	151.51 ± 2.53^{aA}	1657.09 ± 15.60^{bC}	0.01 ± 0.00^{aA}
	Day 15	51.64 ± 0.14^{aD}	2412.09 ± 21.15^{aA}	0.01 ± 0.00^{aA}
	Day 30	51.57 ± 0.14^{aD}	2328.86 ± 27.28^{bA}	0.00 ± 0.00^{bA}
	Day 51	57.50 ± 0.60^{bC}	1954.70 ± 11.79^{aB}	0.01 ± 0.00^{aA}
	Day 72	67.67 ± 0.24^{aB}	1926.23 ± 2.74^{aB}	0.01 ± 0.00^{aA}
	Day 93	51.20 ± 0.72^{bD}	1398.71 ± 7.90^{bD}	0.01 ± 0.00^{aA}
	Day 114	58.78 ± 0.43^{aC}	1559.80 ± 14.85^{bC}	0.01 ± 0.00^{aA}
Potassium sorbate	Day 0	95.06 ± 0.61^{bA}	1764.78 ± 18.42^{aE}	0.01 ± 0.00^{aA}
	Day 15	51.34 ± 0.17^{aF}	1819.55 ± 9.02^{bDE}	0.01 ± 0.00^{aA}
	Day 30	47.53 ± 0.14^{bG}	2477.24 ± 74.83^{aA}	0.01 ± 0.00^{aA}
	Day 51	70.22 ± 0.00^{aB}	1886.49 ± 8.72^{aD}	0.01 ± 0.00^{aA}
	Day 72	62.47 ± 0.52^{bC}	1866.72 ± 19.59^{aDE}	0.01 ± 0.00^{aA}
	Day 93	58.90 ± 0.11^{aD}	2339.91 ± 12.12^{aB}	0.01 ± 0.00^{aA}
	Day 114	52.90 ± 0.12^{bE}	2163.05 ± 18.31^{aC}	0.01 ± 0.00^{aA}

Values with different superscript lowercase letters indicate a statistically significant difference between treatments at the same storage time using Tukey's test ($p \leq .05$).
Values with different superscript uppercase letters indicate a statistically significant difference between storage times within the same treatment using Tukey's test ($p \leq .05$).

Table 3. Changes in the colorimetric values of sugar–free jaboticaba jellies subjected to different preservation methods.

Treatments		L*	a*	b*
Irradiated	Day 0	19.96 ± 0.89^{aAB}	15.33 ± 1.29^{aA}	4.83 ± 0.93^{bA}
	Day 15	20.88 ± 0.58^{aA}	16.60 ± 1.58^{aA}	4.98 ± 1.24^{aA}
	Day 30	19.09 ± 0.62^{aBC}	6.06 ± 1.13^{aB}	0.56 ± 0.21^{bC}
	Day 51	19.60 ± 0.92^{aBC}	5.96 ± 0.80^{aB}	1.48 ± 0.33^{aC}
	Day 72	20.02 ± 0.43^{aAB}	7.90 ± 1.43^{aB}	0.92 ± 0.22^{bC}
	Day 93	18.50 ± 0.78^{aC}	0.89 ± 0.68^{aC}	3.50 ± 0.64^{aB}
	Day 114	18.70 ± 0.48^{aC}	0.92 ± 0.65^{aC}	3.90 ± 1.08^{aAB}
Potassium sorbate	Day 0	16.76 ± 0.78^{bC}	10.20 ± 0.52^{bB}	7.70 ± 0.28^{aA}
	Day 15	19.92 ± 0.64^{bA}	13.67 ± 2.00^{bA}	3.80 ± 1.00^{bB}
	Day 30	18.01 ± 0.96^{bB}	5.76 ± 1.55^{aC}	1.86 ± 0.22^{aCD}
	Day 51	19.85 ± 0.50^{aA}	7.10 ± 1.37^{aC}	1.48 ± 0.44^{aD}
	Day 72	20.08 ± 0.22^{aA}	6.58 ± 0.59^{aC}	1.90 ± 0.21^{aCD}
	Day 93	19.12 ± 0.58^{aAB}	1.06 ± 0.49^{aD}	1.96 ± 0.97^{bCD}
	Day 114	19.08 ± 0.27^{aAB}	1.54 ± 0.75^{aD}	2.78 ± 0.58^{bBC}

Values with different superscript lowercase letters indicate a statistically significant difference between treatments at the same storage time using Tukey's test ($p \leq .05$).
Values with different superscript uppercase letters indicate a statistically significant difference between storage times within the same treatment using Tukey's test ($p \leq .05$).

ingredients on the final and finished product and the changes due to processing (Jan et al., 2020).

During storage, the lightness (L*) and redness (a*) values of the irradiated jellies significantly decreased, indicating darkening and a reduction in the intensity of the red color. This change may be related to the formation of melanoidins, dark brown compounds resulting from the Maillard reaction, and the oxidation of phenolic compounds present in food, which promote typical chromatic changes in fruit-based products (Sirisoontaralak & Noomhorm, 2006). The constant yellowness (b*) value suggests partial stability of the carotenoid or flavonoid pigments that confer yellowish hues (Rodriguez-Amaya, 2010). In contrast, in jellies with potassium sorbate, the increase in lightness (L*) indicates lightening of the product, possibly because of the degradation of natural pigments and a decrease in the concentration of colored compounds. Simultaneously, the decrease in red (a*) and yellow (b*) values may reflect the oxidative degradation of phenolic pigments (such as anthocyanins) and carotenoids, processes influenced by storage and the lack of effective stabilizing treatments (Chamorro et al., 2012).

Figure 1 shows that the total color difference (ΔE*) increased for both formulations during storage, indicating noticeable color changes. However, the irradiated jellies presented significantly higher ΔE* values than those of the jelly with potassium sorbate. This behavior can be explained by the fact that ionizing radiation, although effective in reducing the microbial load, can induce chemical modifications in pigments, especially anthocyanins, through bond cleavage and free radical formation, thereby accelerating color degradation (Hong et al., 2014). Furthermore, irradiation can favor non-enzymatic browning reactions during storage, such as the formation of Maillard products and sugar caramelization, contributing to an increase in b* (yellowish) and a reduction in a* (red) (Sirisoontaralak & Noomhorm, 2006).

The jelly containing potassium sorbate presented a lower ΔE* (Figure 1), a behavior that could be attributed to the slower degradation of pigments, resulting in gradual changes in the L*, a*, and b* parameters. In this formulation, the increase in luminosity (whitening) and moderate reduction in red and yellow tones probably resulted from natural oxidative processes during storage without the intensification caused by radiation (Gliemmo et al., 2009). Potassium sorbate inhibits the growth of fungi and yeasts by interfering with cell membrane permeability and microbial metabolism (Davidson et al., 2013), and does not react directly with phenolic pigments, contributing to partial color preservation compared to that of the irradiated jelly (Preciado-Iñiga et al., 2018). Furthermore, studies have reported that in the absence of additional stresses, such as excessive heat or radiation, anthocyanins and other phenolic pigments undergo slower degradation, thus preserving chromatic intensity for longer periods (Chamorro et al., 2012).

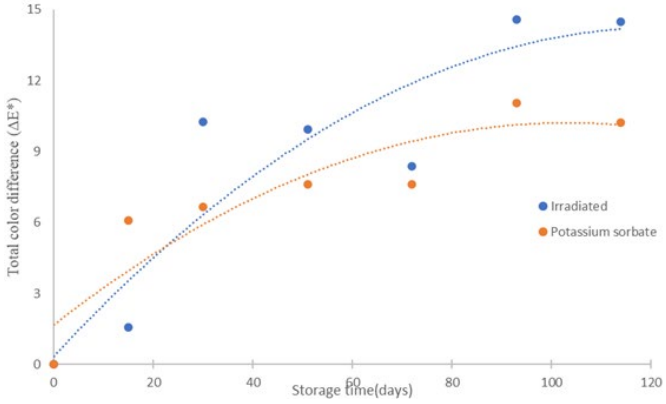

Figure 1. Changes in the total color difference in sugar–free jaboticaba jellies subjected to different preservation methods.

3.2 Degradation of anthocyanins and phenolic compounds

The results presented in Table 4 show that the loss of anthocyanins and phenolic compounds in potassium sorbate–treated jelly was greater than that in irradiated jelly. According to Ito et al. (2019), the kinetic rate constant (k) is an indicator that predicts the thermal degradation of bioactive compounds in food products, with a low value indicating better stability.

The degradation of anthocyanins and phenolic compounds in jellies subjected to gamma irradiation and containing potassium sorbate fitted the first-order kinetic model (Figure 2). For both the evaluated formulations and compounds, a progressive reduction in concentration was observed over storage time, with a good correlation between the experimental data and proposed model, demonstrating that the degradation rate was proportional to the remaining content of the compounds.

This observed behavior (Table 4 and Figure 2) may be related to the fact that potassium sorbate acts predominantly as an antimicrobial agent, inhibiting molds and yeasts by altering cell membrane permeability and interfering with microbial enzyme systems (Davidson et al., 2013), but does not have a direct antioxidant action on phenolic compounds. Therefore, these bioactive compounds remain susceptible to oxidative degradation induced by the presence of dissolved oxygen as well as the light and temperature variations during storage (Patras et al., 2010). In contrast, although irradiation can cause initial degradation of pigments and phenolic compounds through bond cleavage and free radical formation (Fan & Sokorai, 2008), it can also lead to the inactivation of oxidative enzymes such as polyphenol oxidase (PPO) and peroxidase (POD) (Beaulieu et al., 1999; Fan, 2005). The reduced activity of these enzymes during storage can slow the oxidation reactions of phenolics and anthocyanins, resulting in lower k values for the irradiated jelly. Furthermore, the microbial reduction effect promoted by

Table 4. Effect of preservation methods on the reaction rate constant ($days^{-1}$) for the anthocyanin and phenolic compound contents of sugar–free jaboticaba jellies.

Bioactive compounds	Conservation methods	$Kx10^{-2}$ ($days^{-1}$)	R^2
Anthocyanin	Irradiated	1,44	0,91
	Potassium sorbate	1,87	0,98
Phenolic compound	Irradiated	0,30	0,87
	Potassium sorbate	0,33	0,93

radiation contributes to a reduction in metabolic processes that could accelerate the degradation of these compounds.

3.3 Correlation between bioactive compounds, antioxidant capacity, and color parameters

Pearson's correlation coefficients between the levels of bioactive compounds, antioxidant capacity, and color parameters are presented in Table 5. Phenolics were negatively correlated with FRAP ($r = -.72$; $p < .01$). Although phenolic compounds generally contribute positively to the antioxidant capacity assessed using the FRAP method, the negative correlation observed in this study can be attributed to factors that influence the measurement and complexity of the jelly matrix. The FRAP method evaluates the reducing capacity of the antioxidants present; however, it can also be influenced by the presence of other reducing compounds that do not necessarily belong to the phenolic class, such as sugars, organic acids, and degradation products formed during storage (Prior et al., 2005). Furthermore, the degradation of phenolic compounds over time can lead to the formation of oxidation products that still have reducing activity, but are not counted as total phenolics by the method used (Cai et al., 2004). This can lead to an increase in the antioxidant capacity as measured by FRAP, even with a reduction in total phenolic levels, resulting in a negative correlation between these variables. Finally, analytical interference and the possible presence of prooxidant compounds at varying concentrations can affect the results, reinforcing the need for an integrated analysis of multiple antioxidant methods for a more comprehensive assessment (Moharram & Youssef, 2014).

Anthocyanins were positively correlated with a* ($r = .67$; $p < .01$) and b* ($r = .71$; $p < .01$), indicating that higher levels of these pigments were associated with more intense coloration on the red–green axis and more yellowish hues. On the contrary, a significant negative correlation was observed with ΔE* ($r = -.80$; $p < .01$), suggesting that anthocyanin degradation contributes to greater total color changes during storage. Similar results were obtained by Patras et al. (2010) and Steyn et al. (2004), who reported a strong relationship between anthocyanin reduction and loss of color intensity in fruit-based products. The antioxidant capacity determined using the ABTS method showed a significant negative correlation with ΔE* ($r = -.61$; $p < .05$), indicating that greater total color changes are associated with reduced antioxidant activity. This result suggests that the degradation of bioactive pigments, mainly anthocyanins and phenolic compounds, simultaneously contributes to the loss of color intensity and stability, and to the decrease in antioxidant potential. Previous studies have demonstrated that a reduction in anthocyanin content is directly related to a decrease in the antioxidant activity of fruit-based products because of their high capacity to neutralize free radicals (Pérez-Lamela et al., 2021). Furthermore, significant changes in ΔE* reflect chemical and oxidative transformations in pigments, which compromise the overall antioxidant profile of the food (Nkhata, 2020). The a*

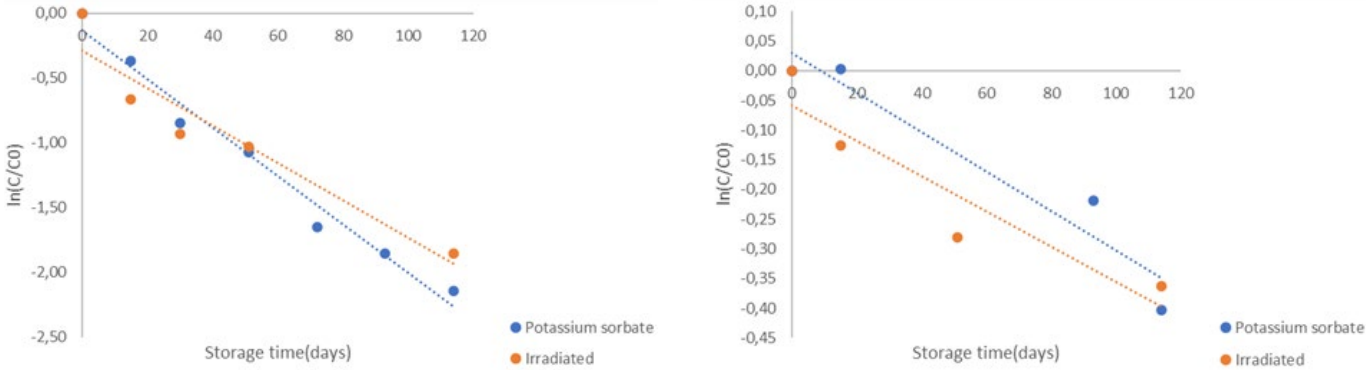

Figure 2. Effect of storage time on the total monomeric anthocyanin and total phenolic compound levels of gamma-irradiated and potassium sorbate–added sugar–free jaboticaba jellies.

Table 5. Pearson correlation coefficients between bioactive compounds, antioxidant capacity, and color parameters.

	Phenolic compound	Anthocyanin	Vitamin C	ABTS	DPPH	FRAP	L*	a*	b*	ΔE*
Phenolic compound	1									
Anthocyanin	0.07	1								
Vitamin C	0.25	0.10	1							
ABTS	−0.15	0.56*	−0.19	1						
DPPH	0.43	−0.14	0.37	−0.38	1					
FRAP	−0.72**	0.07	−0.13	0.16	−0.31	1				
L	−0.20	−0.33	0.20	−0.10	0.14	0.05	1			
a	0.03	0.67**	0.48	0.46	0.08	0.06	0.41	1		
b	−0.36	0.71**	0.25	0.45	−0.35	0.36	−0.36	0.43	1	
ΔE*	−0.02	−0.80**	−0.34	−0.61*	−0.16	−0.15	−0.08	−0.87**	−0.57*	1

*$p < .05$; **$p < .01$.

parameter showed a significant negative correlation with ΔE* ($r = -.87$; $p < .01$), indicating that greater total color changes were associated with decreased intensity on the red–green axis. As previously stated, this relationship suggests that, as red pigments, primarily anthocyanins, degrade, their characteristic hue is lost and the overall color difference is increased during storage. According to Chen et al. (2022), a reduction in the a* parameter is strongly linked to a decrease in red color and an increase in ΔE* in anthocyanin-rich products, owing to their sensitivity to light, oxygen, and pH variations.

The b* parameter was negatively correlated with ΔE* ($r = -.57$; $p < .01$), indicating that greater total color changes were associated with a reduction in yellowish hues (yellow–blue axis), likely owing to the degradation of pigments and other chromophores responsible for the yellow component, which contributed to the increase in the overall color difference.

4 CONCLUSION

This study found that the preservation method and storage time significantly influenced the stability of bioactive compounds, antioxidant capacity, and color parameters of sugar-free jaboticaba jellies. Gamma irradiation proved effective in preserving vitamin C, total phenolic compounds, and antioxidant capacity, thus promoting stability during 114 days of storage, possibly owing to the partial inactivation of oxidative enzymes and stimulation of the biosynthesis of phenolic metabolites. In contrast, the jelly with potassium sorbate showed greater degradation of these compounds, highlighting the limited effectiveness of this preservative in protecting against oxidative processes.

The degradation of anthocyanins and phenolic compounds followed first-order kinetics in both formulations but with a lower degradation rate in the irradiated jelly. The color changes, observed by the parameters L*, a*, b*, and ΔE*, reflect the progressive loss of natural pigments, being more pronounced in the irradiated formulation owing to the action of radiation on the food matrix and non-enzymatic browning reactions.

The significant correlations among anthocyanin levels, antioxidant capacity (ABTS), and color parameters confirm the close relationship between the stability of bioactive compounds and the maintenance of characteristic color in the product. Furthermore, the negative correlation between phenolics and FRAP highlights the complexity of the food matrix and the need for multiple methods to assess antioxidant capacity.

Therefore, gamma irradiation is a promising technology for preserving sugar-free jellies and ensuring greater nutritional stability during storage. Future studies should combine this technology with stabilizing agents specific to anthocyanins to further optimize the quality of the final product.

REFERENCES

Abe-Matsumoto, L. T., Araújo, Y. A., & Medeiros, M. L. (2020). Stability of vitamin c in enriched jelly. *Brazilian Journal of Analytical Chemistry*, *7*(27), 14–19. https://doi.org/10.30744/brjac.2179-3425.AR-38-2019

Alothman, M., Bhat, R., & Karim, A. A. (2009). Effects of radiation processing on phytochemicals and antioxidants in plant produce. *Trends in Food Science & Technology*, *20*(5), 201–212. https://doi.org/10.1016/j.tifs.2009.02.003

Arefin, K. S., Hassan, M., Suny, M. S. H., Sohag, M. M. H., & Farukh, M. A. (2025). Food irradiation technology: an overview of practices and status in the globe and Bangladesh. *Journal of Environmental Science and Natural Resources*, *14*(1–2), 65–71. https://doi.org/10.3329/jesnr.v14i1.81112

Association of Official Analytical Chemists (AOAC) (1984). *Official methods of analysis*. AOAC.

Batista, G. A., Silva, L. G. M., Pereira, M. A., Batista, A. S., Meira, A. C. F. O., Costa, C. A. R., Paiva, T. S., Pio, L. A. S., & Resende, J. V. (2025). Use of Ora-Pro-Nobis (*Pereskia aculeata* miller) mucilage as a substitute for commercial pectin in jaboticaba jelly production. *Revista Observatorio de la Economia Latinoamericana*, *23*(4), e9536. https://doi.org/10.55905/oelv23n4-064

Beaulieu, M., D'Aprano, M. B., & Lacroix, M. (1999). Dose rate effect of gamma irradiation on phenolic compounds, polyphenol oxidase, and browning of mushrooms (*Agaricus bisporus*). *Journal of Agricultural and Food Chemistry*, *47*(7), 2537–2543. https://doi.org/10.1021/jf981088r

Benassi, M. T., & Antunes, A. J. (1998). A comparison of meta-phosphoric and oxalic acids as extractant solutions for the determination of vitamin C in selected vegetables. *Brazilian Archives of Biology and Technology*, *31*, 507–513.

Benzie, I., & Strain, J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. *Analytical Biochemistry*, *239*(1), 70–76. https://doi.org/10.1006/abio.1996.0292

Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free-radical method to evaluate antioxidant activity. *LWT - Food Science and Technology*, *28*(1), 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5

Cai, Y., Luo, Q., Sun, M., & Corke, H. (2004). Antioxidant activity and phenolic compounds of 112 traditional Chinese medicinal plants associated with anticancer. *Life Sciences*, *74*(17), 2157–2184. https://doi.org/10.1016/j.lfs.2003.09.047

Chamorro, S., Goñi, I., Viveros, A., Hervert-Hernández, D., & Brenes, A. (2012). Changes in polyphenolic content and antioxidant activity after thermal treatments of grape seed extract and grape pomace. *European Food Research and Technology*, *234*(1), 147–155. https://doi.org/10.1007/s00217-011-1621-7

Chen, Y., Belwal, T., Xu, Y., Ma, Q., Li, D., Li, L., Xiao, H., & Luo, Z. (2022). Updated insights into anthocyanin stability behavior from bases to cases: Why and why not anthocyanins lose during food processing. *Critical Reviews in Food Science and Nutrition*, *63*(27), 8639–8671. https://doi.org/10.1080/10408398.2022.2063250

Chen, Z., Bertin, R., & Froldi, G. (2013). EC_{50} estimation of antioxidant activity in DPPH● assay using several statistical programs. *Food Chemistry*, *138*(1), 414–420. https://doi.org/10.1016/j.foodchem.2012.11.001

Davidson, P. M., Taylor, T. M., & Schmidt, S. E. (2013). Chemical preservatives and natural antimicrobial compounds. In M. Doyle & L. Beuchat (Eds.), *Food microbiology: fundamentals and frontiers* (3rd ed., pp.765–801). ASM Press.

Dehghan, P., Mohammadi, A., Mohammadzadeh-Aghdash, H., & Dolatabadi, J. E. N. (2018). Pharmacokinetic and toxicological aspects of potassium sorbate food additive and its constituents. *Trends in Food Science & Technology*, *80*, 123–130. https://doi.org/10.1016/j.tifs.2018.07.012

Dionísio, A. P., Gomes, R. T., & Oetterer, M. (2009). Ionizing radiation effects on food vitamins – a review. *Brazilian Archives of Biology and Technology*, *52*(5), 1267–1278. https://doi.org/10.1590/S1516-89132009000500026

Dong, R., Tian, J., Huang, Z., Yu, Q., Xie, J., Li, B., Li, C., & Chen, Y. (2023). Intermolecular binding of blueberry anthocyanins with water-soluble polysaccharides: Enhancing their thermostability and antioxidant abilities. *Food Chemistry*, *410*, 135375. https://doi.org/10.1016/j.foodchem.2022.135375

Einbond, L. S., Reynertson, K. A., Luo, X. D., Basile, M. J., & Kennelly, E. J. (2004). Anthocyanin antioxidants from edible fruits. *Food Chemistry*, *84*(1), 23–28. https://doi.org/10.1016/S0308-8146(03)00162-6

Fan, X. (2005). Antioxidant capacity of fresh-cut vegetables exposed to ionizing radiation. *Journal of the Science of Food and Agriculture*, *85*(6), 995–1000. https://doi.org/10.1002/jsfa.2057

Fan, X., & Sokorai, K. J. B. (2008). Retention of quality and nutritional value of 13 fresh-cut vegetables treated with low-dose radiation. *Journal of Food Science*, *73*(7), S367–S372. https://doi.org/10.1111/j.1750-3841.2008.00871.x

Farias, T. R. T., Schiassi, M. C. E. V., Pereira, P. A. P., Souza, V. R., Lago, A. M. T., Borges, S. V., & Queiroz, F. (2023). Rheological parameters of mixed Brazilian Cerrado fruits sugar-free preserves: the effect of body agents. *Annals of the Brazilian Academy of Sciences*, *95*(1), e20201338. https://doi.org/10.1590/0001-3765202320201338

Ferreira, D. F. (2014). Sisvar: A guide for its bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, *38*(2), 109–112. https://doi.org/10.1590/S1413-70542014000200001

Giovanelli, G., & Buratti, S. (2009). Comparison of polyphenolic composition and antioxidant activity of wild Italian blueberries and some cultivated varieties. *Food Chemistry*, *112*(4), 903–908. https://doi.org/10.1016/j.foodchem.2008.06.066

Gliemmo, M. F., Latorre, M. E., Gerschenson, L. N., & Campos, C. A. (2009). Color stability of pumpkin (*Cucurbita moschata*, Duchesne ex Poiret) puree during storage at room temperature: Effect of pH, potassium sorbate, ascorbic acid and packaging material. *LWT - Food Science and Technology*, *42*(1), 196–201. https://doi.org/10.1016/j.lwt.2008.05.011

Guzik, P., Szymkowiak, A., Kulawik, P., & Zając, M. (2022). Consumer attitudes towards food preservation methods. *Foods*, *11*(9), 1349. https://doi.org/10.3390/foods11091349

Harrison, K., & Were, L. M. (2007). Effect of gamma irradiation on total phenolic content yield and antioxidant capacity of Almond skin extracts. *Food Chemistry*, *102*(3), 932–937. https://doi.org/10.1016/j.foodchem.2006.06.034

Hong, M. J., Kim, J-B., Yoon, T. H., Kim, S. H., Ahn, J-W., Jeong, I. Y., Kang, S-Y., Seo, Y. W., & Kim, D. S. (2014). The effects of chronic gamma irradiation on oxidative stress response and the expression of anthocyanin biosynthesis-related genes in wheat (*Triticum aestivum*). *International Journal of Radiation Biology*, *90*(12), 1218–1228. https://doi.org/10.3109/09553002.2014.934930

Horne, D., Palermo, R., Neumann, M. F., Housley, R., & Bell, J. (2019). Can people accurately estimate the calories in food images? An optimised set of low- and high calorie images from the foodpics database. *Appetite*, *139*, 189–196. https://doi.org/10.1016/j.appet.2019.04.017

Ito, V. C., Zielinski, A. A. F., Demiate, I. M., Spoto, M., Nogueira, A., & Lacerda, L. G. (2019). Effects of gamma radiation on the stability and degradation kinetics of phenolic compounds and antioxidant activity during storage of (*Oryza sativa* L.) black rice flour. *Brazilian Archives of Biology and Technology*, *62*, 19180470. https://doi.org/10.1590/1678-4324-2019180470

Jan, A., Sood, M., Younis, K., & Islam, R. U. (2020). Brown rice based weaning food treated with gamma irradiation evaluated during storage. *Radiation Physics and Chemistry*, *177*, 109158. https://doi.org/10.1016/j.radphyschem.2020.109158

Jenjob, A., Uthairatanakij, A., Jitareerat, P., Wongs-Aree, C., & Aiamla-Or, S. (2017). Effect of harvest seasonal and gamma irradiation on the physicochemical changes in pineapple fruit cv. Pattavia during stimulated sea shipment. *Food Science & Nutrition*, *5*(5), 957–1036. https://doi.org/10.1002/fsn3.485

Kilcast, D. (1994). Effect of irradiation on vitamins. *Food Chemistry*, *49*(2), 157–164. https://doi.org/10.1016/0308-8146(94)90152-X

Kimani, B. G., Takó, M., Veres, C., Krisch, J., Papp, T., Kerekes, E. B., & Vágvölgyi, C. (2023). Activity of binary combinations of natural phenolics and synthetic food preservatives against food spoilage yeasts. *Foods*, *12*(6), 1338. https://doi.org/10.3390/foods12061338

Kitano, K., Fukukawa, T., Ohtsuji, Y., Masuda, T., & Yamaguchi, H. (2002). Mutagenicity and DNA-damaging activity caused by decomposed products of potassium sorbate reacting with ascorbic acid in the presence of Fe salt. *Food and Chemical Toxicology*, *40*(11), 1589–1594. https://doi.org/10.1016/s0278-6915(02)00119-9

Larrauri, J. A., Rupérez, P., & Saura-Calixto, F. (1997). Effect of drying temperature on the stabilitity of polyphenols and antioxidant activity of red grape pomace peels. *Journal of Agricultural and Food Chemistry*, *45*(4), 1390–1393. https://doi.org/10.1021/jf960282f

Leite-Legatti, A. V., Batista, A. G., Dragano, N. R. V., Marques, A. C., Malta, L. G., Riccio, M. F., Eberlin, M. N., Machado, A. R. T., Carvalho-Silva, L. B., Ruiz, A. L. T. G., Carvalho, J. E., Pastore, G. M., & Maróstica Júnior, M. R. (2012). Jaboticaba peel: Antioxidant compounds, antiproliferative and antimutagenic activities. *Food Research International*, *49*(1), 596–603. https://doi.org/10.1016/j.foodres.2012.07.044

Lima, M. B., Assis, F. S., Santos, M. M. O., Santos, P. C., Moreira, F. I., Gomes, R. A. B., Ribeiro, M. C., & Pereira, P. A. P. (2024). Effect of processing and addition of prebiotics on the content of bioactive compounds in seriguela (*Spondias purpurea* L.) juice. *Revista Brasileira de Obesidade, Nutrição e Emagrecimento*, *18*(116), 974–990.

Lima, M. B., Domingos, F. M., Lima, J. J. F. J., Monteiro, R. S., Santos, O. D. H., & Pereira, P. A. P. (2019). Characterization and influence of hydrocolloids on low caloric orange jellies. *Emirates Journal of Food and Agriculture*, *31*(1), 7–15. https://doi.org/10.9755/ejfa.2019.v31.i1.1894

Lima, M. B., Santos, H. V., Barbosa, J. C., Penna, L. O., & Pereira, P. A. P. (2023). Effect of hydrocolloid concentration in low calorie orange jellies on preservation of bioactive compounds and antioxidant capacity. *Annals of the Brazilian Academy of Sciences*, *95*(4), e20191092. https://doi.org/10.1590/0001-3765202320191092

Marathe, S., Deshpande, R., Tripathy, J., & Jamdar, S. N. (2017). Development of shelf stable ready-to-eat vegetable *PULAV* using radiation technology. *Journal of Food Processing and Preservation*, *41*, e13104. https://doi.org/10.1111/jfpp.13104

Marsiglia, W. I. M. L., Oliveira, L. S. C., Almeida, R. L. J., Santos, N. C., Silva Neto, J. M., Santiago, A. M., Melo, B. C. A., & Silva, F. L. H. (2023). Thermal stability of total phenolic compounds and antioxidant activities of jaboticaba peel: Effect of solvents and extraction methods. *Journal of the Indian Chemical Society*, *100*(5), 100995. https://doi.org/10.1016/j.jics.2023.100995

Medina, M. B. (2011). Determination of the total phenolics in juices and superfruits by a novel chemical method. *Journal of Functional Foods*, *3*(2), 79–87. https://doi.org/10.1016/j.jff.2011.02.007

Mesquita, T. C., Schiassi, M. C. E. V., Lago, A. M. T., Careli-Gondim, Í., Silva, L. M., Lira, N. A., Carvalho, E. E. N., & Lima, L. C. O. (2020). Grape juice blends treated with gamma irradiation evaluated during storage. *Radiation Physics and Chemistry*, *168*, 108570. https://doi.org/10.1016/j.radphyschem.2019.108570

Moharram, H. A., & Youssef, M. M. (2014). Methods for determining the antioxidant activity: a review. *Alexandria Journal of Food Science and Technology*, *11*(1), 31–42.

Moura, F. A., Macagnan, F. T., & Silva, L. P. (2015). Oligosaccharide production by hydrolysis of polysaccharides: a review. *International Journal of Food Science and Technology*, *50*(2), 275–281. https://doi.org/10.1111/ijfs.12681

Navikaite, V., Simanaviciute, D., Klimaviciute, R., Jakstas, V., & Ivanauskas, L. (2016). Interaction between κ- and ι-carrageenan and anthocyanins from *Vaccinium myrtillus*. *Carbohydrate Polymers*, *148*, 36–44. https://doi.org/10.1016/j.carbpol.2016.04.059

Nkhata, S. G. (2020). Total color change (ΔE*) is a poor estimator of total carotenoids lost during post-harvest storage of biofortified maize grains. *Heliyon*, *6*(10), e05173. https://doi.org/10.1016/j.heliyon.2020.e05173

Oliveira, M. D. M., Varanda, C. M. R., & Félix, M. R. F. (2016). Induced resistance during the interaction pathogen x plant and the use of resistance inducers. *Phytochemistry Letters*, *15*, 152–158. https://doi.org/10.1016/j.phytol.2015.12.011

Patras, A., Brunton, N. P., O'Donnell, C., & Tiwari, B. K. (2010). Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. *Trends in Food Science & Technology*, *21*(1), 3–11. https://doi.org/10.1016/j.tifs.2009.07.004

Patras, A., Brunton, N. P., & Tiwari, B. K. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food and Bioprocess Technology*, *4*(7), 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Pereira, P. A. P., Souza, V. R., Teixeira, T. R., Queiroz, F., Borges, S. V., & Carneiro, J. D. S. (2013). Rheological behavior of functional sugar-free guava preserves: Effect of the addition of salts. *Food Hydrocolloids*, *31*(2), 404–412. https://doi.org/10.1016/j.foodhyd.2012.11.014

Pérez-Lamela, C., Franco, I., & Falqué, E. (2021). Impact of high-pressure processing on antioxidant activity during storage of fruits and fruit products: a review. *Molecules*, *26*(17), 5265. https://doi.org/10.3390/molecules26175265

Pi, X., Yang, Y., Sun, Y., Wang, X., Wan, Y., Fu, G., Li, X., & Cheng, J. (2022). Food irradiation: a promising technology to produce hypoallergenic food with high quality. *Critical Reviews in Food Science and Nutrition*, *62*(24), 6698–6713. https://doi.org/10.1080/10408398.2021.1904822

Pinto, V. R., Assis, F. S., Dias, A. C. C., Santos, P. C., Barboza, I. V., Cunha, L. R., Gandra, K. M. B., & Pereira, P. A. P. (2024). Effects of storage time and different sugar types on color characteristics, bioactive compounds, and antioxidant capacity of jaboticaba jellies. *DELOS: Desarrollo Local Sostenible*, *17*(53), e1300. https://doi.org/10.55905/rdelosv17.n53-005

Pinto, V. R., Dias, A. C. C., Assis, F. S., Barbosa, L. C., Santos, P. C., Alves, J. J. S., Barboza, I. V., Gomes, C. C. M., Santos, I. S., Monteiro, R. S., Cunha, L. R., Gandra, K. M. B., & Pereira, P. A. P. (2021). The effect of different types of sugars on the physicochemical characteristics, sensory acceptance, and bioactive compounds of jaboticaba jellies. *Journal of Culinary Science & Technology*, *19*, 1–18.

Piper, J. D., & Piper, P. W. (2017). Benzoate and sorbate salts: a systematic review of the potential hazards of these invaluable preservatives and the expanding spectrum of clinical uses for sodium benzoate. *Comprehensive Reviews in Food Science and Food Safety*, *16*(5), 869–880. https://doi.org/10.1111/1541-4337.12284

Plotnikova, I. V., Magomedov, G. O., Zharkova, I. M., Miroshnichenko, E. N., & Plotnikov, V. E. (2022). Jelly formulated with different carbohydrate profiles: quality evaluation. *Foods and Raw Materials*, *10*(2), 262–273. https://doi.org/10.21603/2308-4057-2022-2-535

Preciado-Iñiga, G. E., Amador-Espejo, G. G., & Bárcenas, M. E. (2018). Blanching and antimicrobial mixture (potassium sorbate–sodium benzoate) impact on the stability of a tamarillo (*Cyphomandra betacea*) sweet product preserved by hurdle technology. *Journal of Food Science and Technology*, *55*(2), 740–748. https://doi.org/10.1007/s13197-017-2985-x

Prior, R. L., Wu, X., & Schaich, K. (2005). Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. *Journal of Agricultural and Food Chemistry*, *53*(10), 4290–4302. https://doi.org/10.1021/jf0502698

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, *26*(9–10), 1231–1237. https://doi.org/10.1016/s0891-5849(98)00315-3

Rodriguez-Amaya, D. B. (2010). Carotenoids and food preparation: the retention of pro-vitamin a carotenoids in prepared, processed, and stored foods. In Y. H. Hui (Ed.), *Handbook of food science, technology, and engineering*. CRC Press.

Santos, M. M. O., Assis, F. S., Santos, P. C., Alonso, T. C., Cunha, L. R., Ribeiro, M. C., & Pereira, P. A. P. (2024). Impact of gamma irradiation and slow pasteurization on the quality characteristics of mixed jaboticaba and strawberry juices. *Contribuciones a Las Ciencias Sociales*, *17*(10), 1–25.

Scibisz, I., & Mitek, M. (2009). Effect of processing and storage conditions on phenolic compounds and antioxidant capacity of highbush blueberry jams. *Polish Journal of Food and Nutrition Sciences*, *59*(1), 45–52.

Shinwari, K. J., & Rao, P. S. (2018). Stability of bioactive compounds in fruit jam and jelly during processing and storage: A review. *Trends in Food Science & Technology*, *75*, 181–193. https://doi.org/10.1016/j.tifs.2018.02.002

Sirisoontaralak, P., & Noomhorm, A., (2006). Changes to physicochemical properties and aroma of irradiated rice. *Journal of Stored Products Research*, *42*(3), 264–276. https://doi.org/10.1016/j.jspr.2005.04.001

Souza, P. B. A., Santos, M. F., Carneiro, J. D. S., Pinto, V. R. A., & Carvalho, E. E. N. (2022). The effect of different sugar substitute sweeteners on sensory aspects of sweet fruit preserves: A systematic review. *Journal of Food Processing and Preservation*, *46*(3), e16291. https://doi.org/10.1111/jfpp.16291

Steyn, W. J., Holcroft, D. M., Wand, S. J. E., & Jacobs, G. (2004). Anthocyanin degradation in detached pome fruit with reference to preharvest red color loss and pigmentation patterns of blushed and fully red pears. *Journal of the American Society for Horticultural Science*, *129*(1), 13–19. https://doi.org/10.21273/JASHS.129.1.13

Tavares, I. M. C., Sumere, B. R., Gómez-Alonso, S., Gomes, E., Hermosín-Gutiérrez, I., Da-Silva, R., & Lago-Vanzela, E. S. (2020). Storage stability of the phenolic compounds, color and antioxidant activity of jambolan juice powder obtained by foam mat drying. *Food Research International*, *128*, 108750. https://doi.org/10.1016/j.foodres.2019.108750

Teixeira, G. H. A., Durigan, J. F., Santos, L. O., Hojo, E. T. D., & Cunha Júnior, L. C. (2011). Changes in the quality of jaboticaba fruit (*Myriciaria jaboticaba* (Vell) Berg. cv. Sabará) stored under different oxygen concentrations. *Journal of the Science of Food and Agriculture*, *91*(15), 2844–2849. https://doi.org/10.1002/jsfa.4530

Waterhouse, A. L. (2002). Polyphenolics: determinationof total phenolics. In R. E. Wrolstad (Ed.), *Current protocols in food analytical chemistry* (I1.1.1–I1.1.8).

Xue, H., Zhao, J., Wang, Y., Shi, Z., Xie, K., Liao, X., & Tan, J. (2024). Factors affecting the stability of anthocyanins and strategies for improving their stability: A review. *Food Chemistry*: *X*, *24*, 101883. https://doi.org/10.1016/j.fochx.2024.101883

Yardimci, B. K., Sahin, S. C., Sever, N. I., & Ozek, N. S. (2022). Biochemical effects of sodium benzoate, potassium sorbate and sodium nitrite on food spoilage yeast *Saccharomyces cerevisiae*. *Biologia*, *77*, 547–557. https://doi.org/10.1007/s11756-021-00964-x

Yin, X., Chen, K., Cheng, H., Chen, X., Feng, S., Song, Y., & Liang, L. (2022). Chemical stability of ascorbic acid integrated into commercial products: a review on bioactivity and delivery technology. *Antioxidants*, *11*(1), 153. https://doi.org/10.3390/antiox11010153

Yu, A-N., Tan, Z-W., & Wang, F-S. (2012). Mechanism of formation of sulphur aroma compounds from L-ascorbic acid and L-cysteine during the Maillard reaction. *Food Chemistry*, *132*(3), 1316–1323. https://doi.org/10.1016/j.foodchem.2011.11.111