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Perubahan Kualitas Sirsak Beku-Kering (*Annona muricata* L.) Selama Penyimpanan Suhu Tinggi dengan Berbagai Metode Perlakuan Awal

[Changes in Quality of Freeze-Dried Soursop (Annona muricata L.) During High-Temperature Storage with Various Pre-Treatment Methods]

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ABSTRACT

Soursop (Annona muricata L.) is a tropical fruit rich in dietary fiber, vitamins, and minerals, including vitamin C, which boosts the immune system and prevents premature aging. Due to its high perishability, further processing such as freeze-drying is necessary to extend its shelf life. This study aimed to determine the changes in quality of freeze-dried soursop during storage at 45°C. A factorial completely randomized design (CRD) was used, with two factors: pre-treatment methods (blanching, blanching with citric acid solution, and blanching with salt solution) and storage duration (0, 2, 4, 6, and 8 weeks). Storage at 45°C for 8 weeks significantly affected the chemical (moisture content, antioxidant activity, total flavonoids, and pH) and physical characteristics (color analysis and physical appearance). The results showed a decrease in moisture content, antioxidant activity, total flavonoids, and brightness level (L), while pH, redness (a), and yellowness (b*) increased.*

Keywords: antioxidants, blanching, flavonoids, storage, freeze-dried soursop

ABSTRAK

Sirsak (Annona muricata L.) merupakan buah tropis yang kaya akan serat pangan, vitamin, dan mineral, termasuk vitamin C, yang dapat meningkatkan sistem kekebalan tubuh dan mencegah penuaan dini. Karena sifatnya yang mudah rusak, diperlukan pengolahan lebih lanjut seperti pengeringan beku untuk memperpanjang masa simpannya. Penelitian ini bertujuan untuk mengetahui perubahan mutu sirsak kering beku selama penyimpanan pada suhu 45°C. Rancangan Acak Lengkap (RAL) faktorial yang digunakan adalah rancangan acak lengkap (RAK) dengan dua faktor, yaitu metode praperlakuan (blanching, blanching dengan larutan asam sitrat, dan blanching dengan larutan garam) dan lama penyimpanan (0, 2, 4, 6, dan 8 minggu). Penyimpanan pada suhu 45°C selama 8 minggu berpengaruh nyata terhadap sifat kimia (kadar air, aktivitas antioksidan, total flavonoid, dan pH) dan sifat fisik (analisis warna dan kenampakan fisik). Hasil penelitian menunjukkan terjadi penurunan kadar air, aktivitas antioksidan, total flavonoid, dan tingkat kecerahan (L), sedangkan pH, tingkat kemerahan (a*), dan tingkat kekuningan (b*) meningkat.

Kata kunci: antioksidan, blansing, flavonoid, penyimpanan, sirsak kering beku

Introduction

The soursop plant (Annona muricata L.) originates from the Caribbean, Central America, and South America. It produces edible fruit year-round and is widely used in traditional medicine for treating various conditions, including skin diseases, respiratory issues, fever, bacterial infections, diabetes, hypertension, and cancer (Moghadamtousi et al., 2015; De Souza et al., 2009). Due to its sweet and slightly acidic taste, soursop is often used to make juice. The fruit is also rich in fiber (Teyler, 2002) and contains essential vitamins and minerals. Consuming 100 g of soursop pulp provides approximately 13% of the daily fiber requirement and around 20 mg of vitamin C, which supports the immune system, protects against free radicals, and helps prevent premature aging.

Soursop (Annona muricata) is one of the tropical fruits widely cultivated in Indonesia. Recent data shows that soursop production is spread across various regions in significant quantities. In 2023, Central Java Province recorded a soursop production of 158,700 quintals. Semarang Regency contributed the largest share, producing 23,847 quintals, followed by Purworejo Regency with 23,051.85 quintals (Panturapost, 2023). Meanwhile, in West Java Province, soursop production is also notable. In Bogor City, for example, South Bogor District recorded the highest soursop production, reaching 383 quintals (AyoBogor, 2023). Additionally, Banyumas Regency reported a soursop production of 568.26 quintals in 2024 (Dimassatria Banyumas, 2024). These figures indicate that soursop remains an essential and continuously developing fruit commodity in various regions across Indonesia.Soursop is a high-quality food product, but it is also highly perishable and deteriorates quickly after harvest (Arif et al., 2016). Fresh soursop lasts only 3–4 days due to its high moisture content. Therefore, further processing and storage modifications are necessary to extend its shelf life.

The primary goal of storage is to maintain the quality and condition of food products while protecting them from spoilage. One common method of extending shelf life is reducing moisture content, which in Indonesia is typically done using an oven or cabinet dryer. However, this method is not ideal as it can degrade the fruit's vitamin content, color, and flavor. An alternative solution is freeze-drying, which effectively removes moisture while preserving the fruit's nutritional content and appearance. Freeze-drying is commonly used for food products with heat-sensitive nutrients or high-quality items such as vaccines, bacteria, proteins, or mammalian cells (Nowak & Jakubczyk, 2020).

Color is a crucial component in determining food quality. Therefore, pre-treatment before further processing is essential. Blanching is a common pre-treatment method used for fruits and vegetables to preserve color and inactivate enzymes that cause discoloration and odor. In this study, blanching is particularly important because immature soursop contains high levels of latex, which can react with air and cause browning. Thus, observing changes in quality over time during storage is necessary.

This study is novel as it investigates the quality changes in freeze-dried soursop during storage. The quality assessment was conducted by analyzing both the physical and chemical properties of freeze-dried soursop over a two-month period, with five evaluation points: week 0, week 2, week 4, week 6, and week 8, at a storage temperature of 45°C. The 45°C storage temperature was chosen to accelerate the deterioration process, allowing for a better understanding of the components affected during storage. The analyses conducted include moisture content using a moisture analyzer, color changes using a chromameter, antioxidant activity using the DPPH method, total flavonoid content, pH using the acid titration method, and physical appearance evaluation.

Materials and Methods

Materials and equipments

The materials used in this study include fresh soursop fruit sourced from Porang-Paring Village, Pati, Central Java. The pre-treatment materials consist of distilled water, citric acid, and salt. The materials used for chemical analysis include distilled water, 0.1 N NaOH, 1% phenolphthalein indicator, oxalic acid, DPPH, 75% methanol, 96% ethanol, and quercetin.

The equipment used in this study includes a stainless steel tray, knife, basin, NR-As17AHSS freezer, DW10-N freeze-drying machine, tray, AUX 320 balance, tweezers, MOC63u moisture analyzer, Genesys 105 UV-VIS spectrophotometer, VM-300 vortex mixer, CHIN Spec CS-10 chromameter, and Memmert UM400 incubator.

Experimental design

This study employs a factorial Completely Randomized Design (CRD) with two factors:

1. Pre-treatment methods: blanching, blanching with a 2% citric acid solution, and blanching with a 3% salt solution.
2. Storage duration: 0, 2, 4, 6, and 8 weeks.

Research Parameters

The study consists of chemical and physical appearance analyses:

- Chemical analysis: Moisture content (Moisture Analyzer) (Nurhidayati & Warmiati, 2021), Antioxidant activity (DPPH method) (Inggrid & Santoso, 2015), Total flavonoid content (Ermawati et al., 2023), and pH (Titration method) (Utari et al., 2018).
- Physical appearance analysis: Color change analysis (Chromameter) (Simamora et al., 2022) and Physical appearance evaluation (Utari et al., 2018).

Research Stages

1. Pre-Treatment

Freshly sorted and cleaned soursop was sliced crosswise into pieces 0.5–1 cm thick. The skin and seeds were removed, and the fruit was cut into triangular shapes. The soursop was then divided into three groups based on the pre-treatment method: blanching, blanching with a 2% citric acid solution, and blanching with a 3% salt solution. The pre-treated samples were arranged in thin-walled containers and frozen for 24 hours in a freezer. Once fully frozen, the samples were placed in a freeze-dryer for 57 hours. The dried soursop was then packed in heat-resistant plastic pouches and stored at 45°C in an incubator for eight weeks.

2. Storage Duration

The next stage was the storage process. The freeze-dried soursop samples were stored in an incubator at 45°C for up to eight weeks. Analyses were conducted at weeks 0, 2, 4, 6, and 8. The parameters analyzed included moisture content (measured using a drying oven following the AOAC method) (MDPI, 2021), color change (assessed with a chromameter following the method by Kortei et al.) (Current Science, 2022), antioxidant activity (determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging method based on a modified protocol) (MDPI, 2021), total flavonoid content, pH (measured through the titration method as described by Sifat et al.) (CMUJ, 2023), and physical appearance. The collected data were analyzed using SPSS software with Duncan's multiple range test to determine significant differences between the samples over time.

Results and Discussion

A. Chemical Analysis

Table 1. Summary of Chemical Analysis Results

Factor		Chemical Analysis			
Storage duration	Pre-treatments	Moisture content (%)	Antioxidant activity (%)	Total Flavonoid (%)	pH
0 Week	*Blanching*	6,87±0,06^{gh}	94,85±0,64^{k}	43,17±0,39^{j}	3,87±0,02^{b}
	Blanching + 2% Citric acid	6,99±0,25^{gh}	94,23±0,00^{j}	42,56±0,10^{i}	3,89±0,01^{c}
	Blanching + 3% Salt	7,44±0,15^{i}	94,05±0,13^{j}	42,28±0,10^{i}	3,82±0,01^{a}
2 Weeks	*Blanching*	6,18±0,06^{e}	93,77±0,00^{j}	36,84±0,19^{h}	3,93±0,01^{d}
	Blanching + 2% Citric acid	6,30±0,01^{ef}	92,82±0,37^{i}	35,54±0,10^{f}	3,92±0,01^{d}
	Blanching + 3% Salt	7,17±0,06^{hi}	92,21±0,12^{h}	36,09±0,10^{g}	3,88±0,01^{bc}
4 Weeks	*Blanching*	5,78±0,03^{d}	89,39±0,18^{g}	33,40±0,19^{e}	3,98±0,02^{f}
	Blanching + 2% Citric acid	6,09±0,03^{de}	88,77±0,00^{f}	32,99±0,19^{d}	3,96±0,00^{e}
	Blanching + 3% Salt	6,63±0,11^{fg}	89,12±0,25^{fg}	32,85±0,19^{d}	3,91±0,01^{d}
6 Weeks	*Blanching*	5,26±0,06^{c}	86,78±0,18^{d}	30,38±0,00^{c}	4,07±0,01^{h}
	Blanching + 2% Citric acid	5,72±0,06^{c}	85,85±0,13^{c}	30,52±0,00^{c}	4,03±0,01^{g}
	Blanching + 3% Salt	5,97±0,05^{de}	87,44±0,12^{e}	30,65±0,00^{c}	4,04±0,04^{g}
8 Weeks	*Blanching*	4,54±0,15^{a}	83,70±0,32^{a}	29,21±0,10^{b}	4,74±0,00^{j}
	Blanching + 2% Citric acid	4,91±0,06^{b}	83,48±0,38^{a}	28,73±0,20^{a}	4,08±0,01^{h}
	Blanching + 3% Salt	4,79±0,04^{ab}	85,19±0,25^{b}	29,55±0,19^{b}	4,30±0,00^{i}

**Superscripts indicate significant differences between values within the same column based on Duncan's Multiple Range Test (DMRT) ($p < 0.05$). Identical letters denote no significant difference, while different letters indicate significant variation.*

Moisture content

Table 1 shows that the highest average moisture content was 6.40% in the blanching treatment with a salt solution, while the lowest average moisture content was 5.73% in the blanching treatment without additives. The variation in blanching treatments had a significant effect on the moisture content of freeze-dried soursop. The soursop treated with a salt solution had the highest moisture content compared to blanching alone and blanching with a 2% citric acid solution. This is due to the hygroscopic nature of salt, which binds water within the fruit tissue, preventing its evaporation. Additionally, the presence of citric acid and salt increases the solution concentration, which in turn raises the boiling point.

The concentration of a solution is the ratio between the solvent and solute; the more solute added, the higher the concentration (Putri, 2015). Water has a high molecular density, and when a substance is added, this density increases. This leads to cell wall damage and a faster loss of turgor pressure, allowing water to enter the cells more easily (Yuliani, 2014). This process facilitates faster water absorption into the fruit tissue, resulting in higher moisture content in treatments involving citric acid and salt compared to blanching alone.

It was observed that the moisture content of freeze-dried soursop stored at 45°C for eight weeks gradually decreased. This reduction occurred due to continuous heating at 45°C, which caused further moisture loss. These findings align with those of Rahmanto et al. (2014), who stated that the higher the storage temperature, the lower the product's moisture content.

Antioxidant activity

Table 1 shows that the highest antioxidant activity in freeze-dried soursop was 94.85% in the blanching treatment at week 0, while the lowest antioxidant activity was observed in the blanching treatment with a 2% citric acid solution at week 8, reaching 89.03%. A significant difference was observed in antioxidant activity across the different pre-treatment variations. The blanching treatments had a considerable impact on the antioxidant activity of freeze-dried soursop, with the highest activity recorded in samples subjected to blanching alone, compared to those treated with citric acid or salt solutions. This reduction in antioxidant activity was attributed to the addition of 2% citric acid and 3% salt, which significantly lowered the antioxidant levels in soursop.

The relationship between antioxidants and citric acid is linked to pH levels. Citric acid lowers pH, which affects antioxidant activity by promoting the regeneration of primary antioxidant compounds (Harwono, 2014). A lower pH increases the availability of free H+ ions, which can regenerate antioxidants by binding to phenoxy radicals, thereby restoring antioxidant compounds (Madavi et al., 1996). However, prolonged exposure to heat tends to decrease antioxidant activity due to the degradation of bioactive compounds such as polyphenols, which are sensitive to high temperatures (Susanti, 2008).

The addition of citric acid and salt also increases the solution concentration. Solution concentration is the ratio between solvent and solute; the more solute added, the higher the concentration (Putri, 2015). Water has a high molecular density, and when additional substances are introduced, the density increases, causing cell wall damage and faster loss of turgor pressure, thereby allowing water to penetrate the cells more easily (Yuliani, 2014).

Water absorption into the fruit tissue leads to structural damage due to the increased molecular density. This allows external heat to be transferred into the fruit, resulting in the degradation of certain bioactive components. This aligns with the findings of Farasat et al. (2014), which state that high temperatures cause the loss of bioactive compounds and degradation of antioxidant compounds.

The average highest antioxidant activity in freeze-dried soursop was recorded at week 0 (94.38%), while the lowest was at week 8 (84.12%). Antioxidant activity showed a decreasing trend each week, with an average decline of 2.56% per week. This decrease was attributed to high storage temperatures and prolonged storage duration, both of which contributed to the degradation of bioactive compounds responsible for antioxidant activity. These findings are consistent with Ramdhani et al. (2013), who stated that higher processing temperatures lead to the breakdown of antioxidant compounds, thereby reducing antioxidant activity. Prolonged exposure of freeze-dried soursop to high temperatures for eight weeks resulted in significant antioxidant degradation, leading to an overall decrease in antioxidant activity by 10.26%. Suryaningrum et al. (2006) also highlighted that one of the main weaknesses of antioxidants is their susceptibility to degradation when exposed to oxygen, light, high temperatures, and drying processes.

Total Flavonoid

The highest average total flavonoid content in freeze-dried soursop was recorded at week 0, with a value of 42.67%, while the lowest was observed at week 8, with a value of 29.16% (Table 1). A decline in total flavonoid content was observed each week, with an overall reduction of 13.51% over the storage period. Similar to antioxidant activity, the highest total flavonoid content was found in the blanching-only treatment, compared to blanching with 2% citric acid and 3% salt solution.

This decrease can be attributed to the addition of 2% citric acid and 3% salt, which increased the solution concentration. Solution concentration is the ratio between the solvent and solute; the more solute added, the higher the concentration (Putri, 2015). Water has a high molecular density, and when additional substances are introduced, this density increases, leading to cell wall damage and a faster loss of turgor pressure, allowing water to penetrate the cells more easily (Yuliani, 2014).

The absorption of water into the fruit tissue results in structural damage, as the high molecular density of water, combined with other substances, increases the overall molecular compactness. This facilitates heat transfer into the fruit, leading to the degradation of bioactive compounds, including flavonoids. As shown in Figure 4.3, the total flavonoid content of freeze-dried soursop decreased at an average rate of 3.37% per week due to high storage temperatures and prolonged storage duration. Flavonoid levels tend to decline as temperature increases (Rivana, 2014).

This is because flavonoids are thermolabile (heat-sensitive) compounds, and exposure to high temperatures may cause their degradation through decomposition processes. According to Susanti (2008), chemical composition changes due to high-temperature drying or storage can lead to a reduction in flavonoid content.

pH

Table 1 presents the pH analysis of freeze-dried soursop stored at 45°C for eight weeks using the titration method. The highest pH value recorded was 4.74 in the blanching treatment at week 8, while the lowest pH was 3.82 in the blanching treatment with a salt solution at week 0. The average pH values of freeze-dried soursop at weeks 0, 2, 4, 6, and 8 were 3.86, 3.91, 3.95, 4.05, and 4.37, respectively, indicating a consistent increase in pH over time. The variation in blanching treatments significantly influenced the pH of freeze-dried soursop. The lowest pH was observed in the citric acid treatment, followed by the salt solution, and then blanching alone. This is because citric acid addition lowers the pH of a solution, whereas the addition of salt does not significantly increase the pH of freeze-dried soursop, nor does blanching alone.

The pH of freeze-dried soursop showed a gradual increase throughout the storage period. A significant difference was observed in pH across the different pre-treatment variations. The average pH at week 0 was 3.86, rising to 4.37 at week 8, representing an overall increase of 0.51 over the eight-week storage period. The storage process at 45°C for eight weeks significantly influenced the pH increase. According to Tjahyadi (2008), an increase in acidity in food products may occur due to the breakdown of glucose into acids. Higher temperatures contribute to an increase in pH, albeit not significantly. As the drying temperature and duration increase, the acidity level (pH) tends to rise. This is because organic acids in the fruit gradually evaporate over prolonged drying and storage, leading to an overall increase in pH.

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B. Physical Appearance Analysis

Table 2. Summary of Physical Appearance Analysis

Factor		Color Analysis			Physical Appearance	
Storage duration	Pre-treatment	L*	a*	b*	Color	Shape
0 Week	*Blanching*	79,36±3,40 [hi]	1,30±0,24[a]	21,58±0,25[bc]	White	Irregular Triangle
	Blanching + 2% citric acid	75,50±2,45 [fg]	1,16±0,01[a]	23,17±1,27[d]	White	Irregular Triangle
	Blanching + 3% salt	80,82±0,41 [i]	1,24±0,08[a]	21,18±0,79[b]	White	Irregular Triangle
2 Weeks	*Blanching*	77,84±0,06 [gh]	1,49±0,04[a]	19,73±0,03[a]	Ivory White	Irregular Triangle
	Blanching + 2% citric acid	68,29±0,17 [cd]	4,71±0,08[c]	31,49±0,06[h]	Brownish White	Irregular Triangle
	Blanching + 3% salt	72,03±1,04 [e]	1,05±0,02[a]	22,24±0,46[cd]	Ivory White	Irregular Triangle
4 Weeks	*Blanching*	74,68±1,03 [f]	3,14±0,11[b]	23,19±0,11[d]	Ivory White	Irregular Triangle
	Blanching + 2% citric acid	63,14±0,90 [b]	10,46±0,83 [f]	33,75±0,78[i]	Light Brown	Irregular Triangle
	Blanching + 3% salt	75,17±,39[f]	4,19±0,61[c]	24,30±0,01[e]	Brownish White	Irregular Triangle
6 Weeks	*Blanching*	67,58±0,08 [cd]	7,11±0,03[e]	30,32±0,05[g]	Brownish White	Irregular Triangle
	Blanching + 2% citric acid	65,74±0,01 [c]	12,22±0,04 [g]	36,14±0,03[j]	Brown	Irregular Triangle
	Blanching + 3% salt	69,71±0,03 [de]	5,94±0,01[d]	28,23±0,03[f]	Brownish White	Irregular Triangle
8 Weeks	*Blanching*	59,14±0,06 [a]	13,06±0,04 [h]	33,69±0,06[i]	Light Brown	Irregular Triangle
	Blanching + 2% citric acid	58,06±0,05 [a]	13,96±0,01 [i]	34,66±0,04[i]	Dark Brown	Irregular Triangle
	Blanching + 3% salt	62,05±0,03 [b]	12,21±0,02 [g]	34,20±0,03[i]	Light Brown	Irregular Triangle

**Superscripts indicate significant differences between values within the same column based on Duncan's Multiple Range Test (DMRT) ($p < 0.05$). Identical letters denote no significant difference, while different letters indicate significant variation.*

*Lightness (L)**

Table 2 presents the L* (lightness) values of freeze-dried soursop, indicating that the highest L* value (80.82) was observed in the blanching treatment with a salt solution at week 0, while the lowest L* value (58.06) was recorded in the blanching treatment with a citric acid solution at week 8. The data show a consistent decline in L* values over the eight-week storage period at 45°C, suggesting a gradual darkening of the samples.

L* values range from white to black, meaning that lower L* values indicate darker samples. As the storage duration increased at 45°C, the L* values progressively decreased. This color change can be attributed to non-enzymatic browning reactions occurring in freeze-dried soursop. One of the main reactions involved is caramelization, which causes the initially white color of the fruit to turn brown. This caramelization process is the primary factor contributing to the reduction in L* values over time.

Redness (a)*

Table 2 presents the a* (redness) values of freeze-dried soursop, showing that the highest a* value (13.96) was observed in the blanching treatment with a citric acid solution at week 8, while the lowest a* value (1.16) was recorded in the same treatment at week 0. The data indicate a progressive increase in a* values over the eight-week storage period at 45°C, signifying an intensification of the red hue in the samples.

Higher a* values correspond to a stronger red coloration. As the storage duration increased at 45°C, the a* values consistently rose, suggesting that the samples became redder over time. This color change is primarily attributed to non-enzymatic browning reactions in freeze-dried soursop, particularly caramelization. Caramelization leads to a transformation of the initial white color into a brownish hue, contributing to the observed rise in a* values.

Yellowness (b)*

Table 2 presents the b* (yellowness) values of freeze-dried soursop, showing that the highest b* value (36.14) was recorded in the blanching treatment with a citric acid solution at week 6, while the lowest b* value (21.18) was observed in the blanching treatment with a salt solution at week 0. The data indicate a progressive increase in b* values over the eight-week storage period at 45°C, signifying an intensification of the yellow hue in the samples.

Higher b* values correspond to a more pronounced yellow coloration. As storage duration increased at 45°C, the b* values consistently rose, suggesting that the samples became more yellow over time. This color change is primarily attributed to non-enzymatic browning reactions in freeze-dried soursop, particularly caramelization. Caramelization leads to a transformation of the initially white color into a brownish hue, contributing to the observed increase in b* values.

Physical appearance

The analysis of physical appearance was conducted to observe changes in shape and color during storage using direct visual assessment, without the aid of specialized instruments. The tools used included Petri dishes for sample placement, white paper as a background, and a camera for documentation.

Table 2 presents the findings on physical appearance. At week 0, freeze-dried soursop was white and irregularly triangular in all treatment groups. As storage progressed, color changes were observed. By week 2, samples from treatments B1F2 and B1F3 changed from white to ivory, while B2F2 exhibited a slightly brownish-white color. By week 4, B1F3 remained ivory, B2F3 turned light brown, and B3F3 became slightly brownish-white. At week 6, B1F4 and B3F4 exhibited a slightly brownish-white hue, while B2F4 became brown. By week 8, drastic color changes were noted, with B2F5 turning dark brown and B1F5 and B3F5 becoming light brown. However, the shape of freeze-dried soursop remained unchanged, retaining its irregular triangular form throughout the eight-week storage period.

Browning is a natural or process-induced phenomenon in food products, occurring independently of added colorants (Hasan, 2016). Browning reactions are categorized into enzymatic and non-enzymatic types (Winarno, 2004). Enzymatic browning results from the activity of polyphenol oxidase and phenol oxidase in the presence of oxygen. In contrast, non-enzymatic browning occurs without enzymatic influence, typically during food processing. Non-enzymatic browning is closely related to protein and carbohydrate reactions, particularly sugar derivatives (Suryani et al., 2014). The three primary types of non-enzymatic browning include caramelization, the Maillard reaction, and browning due to vitamin C degradation.

In this study, the observed color changes were attributed to non-enzymatic caramelization. During storage, caramelization reactions occurred due to the natural sugar content in freeze-dried soursop. Storage at 45°C for eight weeks intensified caramelization, leading to darkening of the fruit. Continuous heating caused sugars to undergo caramelization, progressively changing the color of freeze-dried soursop from white to dark brown. This transformation occurred because freeze-drying concentrates the sugar content by removing moisture, and subsequent heating during storage triggered browning reactions.

Conclusion

1. Storage at 45°C for eight weeks had a significant impact on the chemical characteristics (moisture content, antioxidant activity, total flavonoid content, and pH) and physical characteristics (color analysis and physical appearance) of freeze-dried soursop.
2. Storage at 45°C for eight weeks resulted in a decrease in moisture content (%), antioxidant activity (%), total flavonoid content (%), and lightness (L*), while an increase was observed in pH, redness (a*), and yellowness (b*).
3. Significant differences were observed in the quality of freeze-dried soursop across different pre-treatment variations.
4. Based on color feasibility parameters, the best freeze-dried soursop during eight weeks of storage at 45°C was obtained from the blanching treatment with a salt solution. This treatment exhibited the least changes compared to blanching alone and blanching with a citric acid solution. The final characteristics of the best treatment were as follows: moisture content of 4.79%, antioxidant activity of 85.18%, total flavonoid content of 29.55%, pH of 4.30, lightness (L*) of 62.05, redness (a*) of 12.21, and yellowness (b*) of 34.2.

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