



Effect of Sugar Concentration on Microbiological and Physicochemical Stability of Soursop Jam

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Abstract: Soursop jam is a local fruit-based product with potential for food diversification; however, its high moisture content increases susceptibility to microbiological deterioration during room-temperature storage. This study aimed to evaluate the effect of different sugar concentrations on the microbiological, physicochemical, and sensory characteristics of soursop jam and to determine its shelf life using a critical limit and risk-based microbiological assessment approach. The novelty of this study lies in the integration of microbiological indicators with physicochemical parameters to explain biological failure during storage of local fruit-based jam products. The experiment used three sugar concentrations, namely 50%, 60%, and 70% (w/w), with duplicate analyses for each treatment. Storage observations were conducted for 20 days at room temperature (27–30 °C), while microbiological analysis referred to ISO 4833-1:2013 and SNI 3746:2008 as the critical microbiological limit. The results showed that initial Total Plate Count values ranged from 23.50×10^3 to 34.00×10^3 CFU g⁻¹, which remained below the permissible limit. Moisture content decreased from 48.36% to 36.80% with increasing sugar concentration, while vitamin C content increased from 7.86 to 10.48 mg/100 g. The jam with 60% sugar concentration showed the highest sensory acceptance scores for color (4.64 ± 0.42) and aroma (4.78 ± 0.40). However, visible mold and yeast growth appeared after 20 days of storage in all treatments. Based on the critical limit approach, the shelf life of soursop jam is recommended not to exceed one week under room-temperature storage conditions.

Keywords: Food safety; Microbiological stability; Shelf life; Soursop jam; Sugar concentration

Introduction

Fruit-based processed foods play an important role in extending the utilization of local agricultural commodities while improving their economic and nutritional value. Among various fruit products, jam is widely produced due to its relatively simple processing method, long-standing consumer acceptance, and versatility as a food ingredient. Soursop (*Annona muricata* L.) is a tropical fruit with distinctive flavor and high vitamin C content; however, its high moisture content and acidic nature make it highly susceptible to

microbial spoilage during storage. These characteristics pose challenges for maintaining product stability and safety, particularly under room temperature conditions. The development of locally processed agricultural commodities also contributes to sustainable agro-industrial development and value-added diversification of regional food resources (Bengi et al., 2025).

The utilization of local fruit resources for jam production has also been widely explored to increase the added value of agricultural commodities and improve food diversification. Previous studies on pineapple jam and mixed-fruit jam products demonstrated that sugar

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concentration significantly affects physicochemical stability and organoleptic characteristics of fruit-based products (Lalujan et al., 2025). Previous studies on processed soursop-based products also demonstrated that sugar concentration significantly affects moisture content, color, taste, and overall physicochemical quality of food products derived from soursop materials (Haryanto, 2018). Nevertheless, most studies primarily focus on formulation optimization without integrating microbiological risk evaluation into shelf-life determination.

Food safety and hygiene are critical aspects in the development of processed local food products, particularly those stored at room temperature. Previous studies have emphasized that inadequate sanitation practices, poor hygiene control, and improper storage conditions significantly contribute to microbial contamination and reduced shelf life of food products (Jannah et al., 2023; Ridawati et al., 2023; Zaitun, 2024). In traditional and small-scale food processing systems, microbiological deterioration remains one of the main challenges affecting food quality and consumer safety.

Previous studies on fruit jam products have generally focused on formulation optimization, physicochemical characteristics, and sensory acceptance, particularly related to sugar concentration and texture development (Lalujan et al., 2025; Rahayu et al., 2026). Similar formulation-based studies in functional food products also demonstrated that variations in ingredient composition significantly affect physicochemical properties and sensory acceptance of processed food products (Simamora et al., 2026). Previous studies on jam products also demonstrated that sugar concentration significantly affects moisture content, texture, color, aroma, and consumer acceptance, indicating the important role of sugar in determining overall jam quality characteristics (Arsyad, 2018).

Although these studies demonstrated that sugar concentration influences moisture content, acidity, and consumer preference, microbiological stability during storage has received considerably less attention. In many locally processed fruit products, shelf-life determination is still primarily based on sensory deterioration or physicochemical changes, without clear integration of microbiological safety indicators.

This limitation is important because fruit jams with relatively high moisture content and room-temperature storage conditions remain vulnerable to microbial contamination, particularly by molds and yeasts. In tropical fruit commodities, postharvest deterioration remains a major challenge due to rapid physiological and chemical changes after harvest, making processing technologies such as jam production important for improving product stability and utilization of local agricultural resources (Rosadalima et al., 2022).

Under such conditions, products may appear organoleptically acceptable even after microbiological deterioration has begun, potentially increasing food safety risks for consumers. Therefore, shelf-life evaluation based solely on sensory or chemical parameters may not adequately represent the actual biological safety status of the product.

The novelty of this study lies in the integration of microbiological indicators with physicochemical and sensory parameters using a critical limit and risk-based microbiological assessment approach to identify the biological failure phase of soursop jam during room-temperature storage. Unlike previous studies that mainly emphasized product formulation and sensory quality, this research evaluates shelf life based on microbiological safety thresholds supported by moisture content, pH, vitamin C stability, and visual fungal growth. This approach is important for improving scientific understanding of food stability in locally processed fruit products and for supporting safer small-scale food processing practices. To the best of our knowledge, studies integrating microbiological critical limits with physicochemical stability assessment in soursop jam are still very limited.

Therefore, the objective of this study was to evaluate the effect of different sugar concentrations on the microbiological, physicochemical, and sensory characteristics of soursop jam and to determine its shelf life at room temperature using a critical limit and risk-based microbiological assessment approach.

Method

Time and Place of the Research

This study was conducted from July, 2025 to October, 2025 at the Laboratory of Food Technology, Faculty of Agricultural Technology, Artha Wacana Christian University, Kupang, East Nusa Tenggara, Indonesia. Microbiological analyses were performed at the Food Microbiology Laboratory, while physicochemical analyses were carried out in the Food Chemistry Laboratory of the same institution.

Research Design

This study was designed as a laboratory experimental research using a Completely Randomized Design (CRD) with three sugar concentration treatments (50%, 60%, and 70% w/w based on soursop pulp weight), each conducted in duplicate (Montgomery, 2017). The CRD was selected as it is well-suited for homogeneous laboratory conditions where environmental effects can be adequately controlled (Steel et al., 1997).

The population of this study was soursop jam (*Annona muricata* L.) produced under controlled

laboratory conditions. The sample consisted of soursop jam at three sugar concentration levels, representing the practical range applied in fruit jam formulation. Samples were taken at predetermined storage time points (day 0 and day 20) using purposive sampling based on the specified observation intervals of the study (Campbell et al., 2020).

The independent variable was sugar concentration (50%, 60%, 70%). The dependent variables were: total plate count (TPC), pH, moisture content, vitamin C content, and sensory attributes (color and aroma). Controlled variables included soursop pulp quantity, cooking temperature (~100 °C), cooking duration (~7 minutes), storage temperature (27–30 °C), and container type.

Data were collected through laboratory measurement and structured observation, including microbiological enumeration (TPC), instrumental physicochemical measurements, and hedonic sensory evaluation (Meilgaard et al., 2015). Tools and materials used in the research: main materials included ripe soursop fruit with uniform maturity, commercial granulated sugar, clean water, Plate Count Agar (PCA) medium, buffer solutions, pH indicators, and iodometric titration reagents. Equipment consisted of an analytical balance, heating stove, stainless steel cooking pan, blender, calibrated pH meter, drying oven, microbiological incubator, Petri dishes, autoclave, and standard laboratory glassware.

Research Procedure

Step 1 – Raw material preparation. Ripe soursop fruits with uniform maturity were washed, peeled, and deseeded. The flesh was blended to obtain a homogeneous pulp.

Step 2 – Jam processing. The pulp was cooked with granulated sugar according to each treatment concentration (50%, 60%, or 70% w/w) at approximately 100 °C for 7 minutes until a homogeneous jam consistency was achieved.

Step 3 – Packaging and storage. The jam was cooled to room temperature, filled into sterile containers, sealed, and stored at room temperature (27–30 °C) for 20 days.

Step 4 – Microbiological analysis. Total Plate Count (TPC) was performed at day 0 using the pour plate method on PCA medium following ISO 4833-1:2013 (ISO 4833-1, 2013a). Visual observation of mold and yeast growth was conducted throughout 20 days of storage as a critical limit indicator.

Step 5 – Physicochemical analysis. Moisture content was determined by oven-drying (AOAC 934.01), pH was measured using a calibrated pH meter, and vitamin C content was analyzed by iodometric titration (AOAC 967.21) at designated observation intervals.

Step 6 – Sensory evaluation. A descriptive hedonic test for color and aroma was conducted by semi-trained panelists using a five-point scale at day 0 and day 20.

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Step 5 – Physicochemical analysis. Moisture content was determined by oven-drying to constant weight according to AOAC 934.01 (AOAC, 2019). pH was measured using a calibrated pH meter. Vitamin C content was analyzed using the iodometric titration method following AOAC 967.21 (AOAC, 2019).

Step 6 – Sensory evaluation. A descriptive hedonic test focusing on color and aroma was conducted by semi-trained panelists using a five-point hedonic scale to assess consumer acceptance of each treatment (Meilgaard et al., 2016). Evaluation was performed at day 0 and day 20.

Research Data Analysis

Data from microbiological, physicochemical, and sensory analyses were analyzed using one-way Analysis of Variance (ANOVA) at a significance level of $\alpha = 0.05$ (Montgomery, 2017). When significant differences were detected among treatments, Duncan's Multiple Range Test (DMRT) was applied to identify specific differences between treatment means (Duncan, 1955; Steel et al., 1997).

Shelf-life determination was performed using a critical limit approach, integrating TPC results, visual observation of mold and yeast growth, and physicochemical parameters as indicators of biological failure during room-temperature storage. This approach follows food safety risk-based microbiological assessment frameworks (Susilowati et al., 2012).

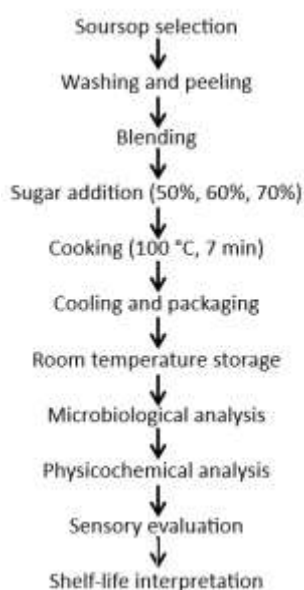


Figure 1. Research workflow for sourstop jam processing and stability evaluation. Click or tap here to enter text. Click or tap here to enter text (ISO 4833-1, 2013b; SNI 3746, 2008)

Result and Discussion

Microbiological Characteristics and Shelf Life of Soursop Jam

The results of the Total Plate Count (TPC) analysis at the initial storage stage (day 0) showed that all sourstop jam treatments with different sugar concentrations (50%, 60%, and 70%) had microbial counts below the maximum permissible limit for fruit jam according to the Indonesian National Standard (SNI) (Table 1). These findings indicate that the initial processing steps, particularly heat treatment and sugar addition, were effective in suppressing microbial growth during the early phase of storage.

Table 1. Total Plate Count (TPC) of Soursop Jam at Initial Storage (Day 0) Under Different Sugar Concentrations

Sugar concentration (%)	TPC (CFU g ⁻¹) ×10 ³ ± SD
50 (P1)	34.0 ± 2.8
60 (P2)	30.5 ± 2.1
70 (P3)	23.5 ± 3.5

Values are expressed as mean ± standard deviation (SD) calculated from duplicate measurements at 10⁻³ dilution

The effective microbial control observed at the initial storage stage is associated with the combined effects of high processing temperature and osmotic pressure induced by sugar addition. Heating at temperatures close to 100 °C reduces the population of vegetative microorganisms, while sugar lowers the availability of free water required for microbial metabolism and growth.

However, visual observation during storage revealed that after 20 days of storage at room temperature, all treatments exhibited visible growth of molds and yeasts (Figure 2).



Figure 2. Visual appearance of sourstop jam after 20 days of storage at room temperature

This condition indicates that the product had exceeded the critical microbiological limit, and therefore was no longer recommended for consumption. Within the applied science (IPA) framework, this situation represents a biological failure phase, in which the food system is no longer capable of naturally inhibiting microbial activity.

The critical limit approach applied in this study emphasizes that food safety is not determined solely by initial microbial conditions (FAO & WHO, 2021), but also by the dynamic changes in the microbiological environment during storage (Pawar et al., 2026). Although higher sugar concentrations were effective in suppressing microbial growth at the beginning of storage (Taiwo et al., 2024), the combined effects of moisture content, pH, and ambient temperature were insufficient to maintain long-term microbiological stability (Jha et al., 2026).

Microbiological Risk Analysis Based on Physicochemical Parameters

The decline in microbiological stability of sourstop jam during storage can be explained through a risk-based microbiological assessment that considers key physicochemical parameters, namely moisture content, pH, and sugar concentration, as also reflected in previous studies on the storage stability of sourstop-based products (Rababah et al., 2014; Scrob et al., 2022). The relatively high moisture content of the sourstop jam (36–48%) provides sufficient free water to support microbial metabolic activity, particularly that of molds and yeasts (Žlabur et al., 2021).

Although sugar has the capacity to reduce water activity through osmotic pressure, its effectiveness

strongly depends on sugar concentration and storage conditions. Under room temperature storage, osmotolerant microorganisms are still capable of growing in products with intermediate moisture content, especially when storage duration is prolonged.

The pH values of the soursop jam, ranging from 3.83 to 4.05, are sufficiently acidic to inhibit the growth of most pathogenic bacteria. Similar acidic characteristics were also reported in dragon fruit peel-soursop jam formulations, where the resulting jam products showed pH values favorable for gel formation and sensory acceptance (Rosadalima et al., 2022). However, these conditions remain favorable for the growth of acidophilic microorganisms, particularly yeasts and molds. This explains why product deterioration during storage was predominantly characterized by fungal growth rather than bacterial spoilage. Similar findings were reported in studies on traditional food safety, where biological contamination was closely associated with storage conditions, environmental exposure, and sanitation practices during food handling (Roza et al., 2025).

In addition, the heat treatment applied during jam processing (approximately 7 minutes at near-boiling temperature) may not have been sufficient to completely inactivate heat-resistant microbial spores. Residual spores can regain metabolic activity during storage when environmental conditions become favorable. Previous studies have also emphasized the importance of antimicrobial control strategies and sanitation management in suppressing microbial contamination in food systems (Lubis et al., 2025). Based on the risk-based microbiological assessment applied in this study, the shelf life of soursop jam under the experimental conditions is therefore recommended not to exceed one week of storage at room temperature.

Moisture Content of Soursop Jam

Analysis of variance (ANOVA) showed that variations in sugar concentration had a highly significant effect ($P < 0.01$) on the moisture content of soursop jam (Figure 3). The treatment with a 50% sugar concentration resulted in the highest moisture content, whereas the treatment with a 70% sugar concentration produced the lowest moisture content. Similar effects of sugar concentration on moisture reduction and vitamin C characteristics have also been reported in fruit marmalade products, where moderate sugar levels contributed to improved physicochemical stability and product acceptability (Picauly et al., 2025).

The decrease in moisture content with increasing sugar concentration demonstrates the role of sugar as a dehydrating agent through an osmotic pressure mechanism. Similar trends have been reported in fruit-based jelly products, where increasing sugar

concentration reduced moisture content while contributing to vitamin C stability and product acceptability (Kubela et al., 2023). Sugar binds free water molecules within the food matrix (Kawai et al., 2014), thereby reducing the availability of water required for microbial growth and metabolic activity (Belitz et al., 2009). Similar findings in papaya jam products showed that increasing sucrose concentration reduced water-related instability and significantly affected the physical characteristics of the final product (Rochmah et al., 2019). Similar findings were reported in carica jam products, where increasing sugar concentration significantly reduced moisture content and water activity, thereby contributing to improved product stability during storage (Mukminah et al., 2022). The role of sugar in modifying physicochemical properties has also been reported in other agricultural products, where sugar composition significantly affected product quality and stability (Syamsiar et al., 2025).

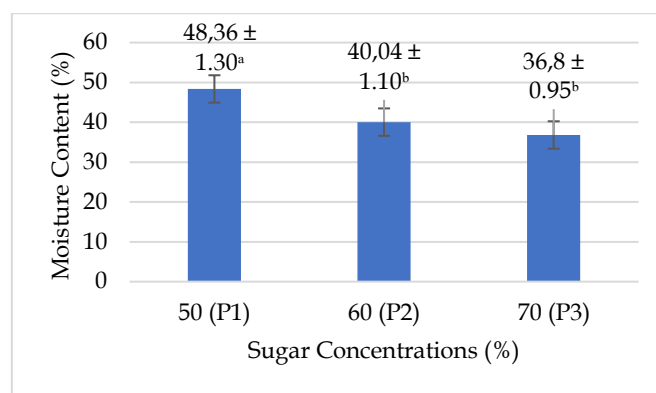


Figure 3. Moisture content of soursop jam at different sugar concentrations

Lower moisture content contributes directly to improved product stability, particularly by limiting the growth of spoilage microorganisms (Vermelho et al., 2024). In this study, the moisture content of soursop jam produced with 60% and 70% sugar concentrations remained within the recommended range for fruit jam according to the Indonesian National Standard (SNI) (SNI 3746, 2008), which is 30–40%. Therefore, these treatments are technically more favorable for product stability compared to the 50% sugar treatment, which exhibited moisture content above the recommended limit.

pH Values of Soursop Jam

Analysis of variance (ANOVA) indicated that sugar concentration had a highly significant effect ($P < 0.01$) on the pH values of soursop jam (Figure 4). The treatment with a 50% sugar concentration resulted in the highest pH value, whereas treatments with 60% and 70% sugar concentrations exhibited lower pH values. Previous

studies also demonstrated that higher sugar concentrations contribute to a more stable physicochemical environment, including pH stability in fruit-based jam products (Zeng et al., 2021).

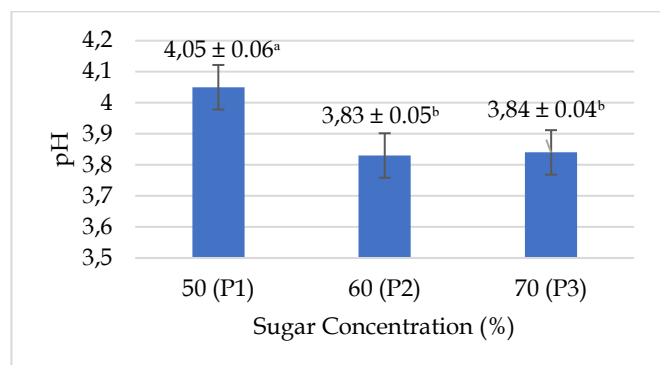


Figure 4. pH of soursop jam at different sugar concentrations

The differences in pH values are associated with the interaction between sugar concentration and natural organic acids present in fruit matrices (Rababah et al., 2014). Higher sugar concentrations may influence the dissociation and perception of organic acids within the jam matrix (L. Zhang et al., 2024), resulting in slightly lower pH values.

Lower pH values contribute to improved microbiological safety by inhibiting the growth of most pathogenic bacteria. However, the pH range observed in this study (3.83–4.05) remains favorable for the growth of acidophilic microorganisms, particularly yeasts and molds. This finding is consistent with the observed dominance of fungal growth during extended storage at room temperature.

Vitamin C Content of Soursop Jam

The analysis showed that variations in sugar concentration had a highly significant effect ($P < 0.01$) on the vitamin C content of soursop jam (Figure 5). The treatment with a 70% sugar concentration resulted in the highest vitamin C content, whereas the treatment with a 60% sugar concentration exhibited the lowest value. Previous studies on fruit jam products also reported that sugar concentration influences antioxidant-related compounds and overall physicochemical stability during storage (Banaš et al., 2018).

The higher stability of vitamin C observed at higher sugar concentrations is likely associated with reduced water activity and limited exposure of vitamin C to oxygen during the heating process (Giannakourou & Taoukis, 2021). Vitamin C is highly susceptible to oxidative degradation; therefore, conditions with lower free water content tend to slow down oxidation reactions and reduce nutrient loss.

In treatments with lower sugar concentrations, a greater amount of free water may facilitate the dissolution and oxidation of vitamin C during heating, leading to higher degradation rates, as also reported in fruit jam systems using different sweetener formulations (Scrob et al., 2022). These findings indicate that sugar concentration plays a dual role in soursop jam processing, functioning not only as a sweetening agent but also as a protective factor for vitamin C stability.

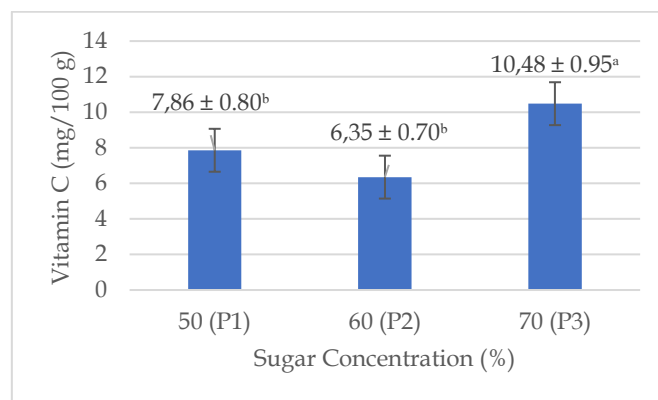


Figure 5. Vitamin C content of soursop jam at different sugar concentrations

Sensory Characteristics of Soursop Jam

The sensory evaluation results indicated that sugar concentration had a highly significant effect ($P < 0.01$) on the color and aroma attributes of soursop jam (Table 2). Among the treatments, the jam formulated with a 60% sugar concentration received the highest acceptance scores for both sensory attributes.

Table 2. Average sensory scores for color and aroma of soursop jam at different sugar concentrations

Sugar concentration (%)	Color score ±SD	Aroma score ± SD
50 (P1)	2.87 ± 0.48 ^c	2.82 ± 0.50 ^c
60 (P2)	4.64 ± 0.42 ^a	4.78 ± 0.40 ^a
70 (P3)	3.73 ± 0.46 ^b	3.69 ± 0.44 ^b

Values are expressed as mean ± standard deviation (SD). Different superscript letters within the same column indicate significant differences at $P < 0.01$ (Duncan’s multiple range test).

Sugar concentration plays an important role in determining sensory acceptance of fruit-based jam products. Higher sugar concentrations generally improve color intensity, aroma perception, sweetness balance, and texture characteristics, thereby increasing overall consumer preference (Almaghouth et al., 2023; Quitral et al., 2019). The interaction between sugar and acidic compounds also contributes to flavor perception and affects the sensory evaluation of fruit products (Mao et al., 2022). Similar sensory studies demonstrated that products formulated with appropriate sugar concentrations tend to receive higher preference scores

due to improved sweetness, texture, and flavor balance (Rana et al., 2021). However, increasing consumer awareness regarding healthier food choices has encouraged interest in lower-sugar fruit products that maintain acceptable sensory quality without excessive sugar addition (Rana et al., 2021). However, increasing consumer awareness regarding healthier food choices has encouraged interest in lower-sugar fruit products that maintain acceptable sensory quality without excessive sugar addition (Nistor et al., 2021).

Previous work has indicated that storage significantly affects both physicochemical attributes and microbial stability in fruit jams, with changes strongly influenced by storage duration and conditions (El Hosry et al., 2025). The optimal balance between non-enzymatic browning reactions and the formation of characteristic jam aroma was achieved at the moderate sugar concentration (60%). At lower sugar concentrations, browning reactions were less pronounced, resulting in a paler and less attractive color (Zhang et al., 2022). In contrast, excessive sugar concentration tended to suppress the perception of natural fruit aroma due to the dominance of sweetness (Lund & Ray, 2017).

Overall, the treatment with a 60% sugar concentration exhibited the most favorable balance among microbiological stability, physicochemical characteristics, and sensory acceptance, indicating that this formulation is the most suitable for producing soursop jam with desirable quality attributes (FAO & WHO, 2021; Pawar et al., 2026; Taiwo et al., 2024; Jha et al., 2026; Žlabur et al., 2021; Kawai et al., 2014; Belitz et al., 2009; Vermelho et al., 2024; SNI 3746, 2008; SNI 3746, 2008; Rababah et al., 2014; Zhang et al., 2024; Giannakourou & Taoukis, 2021; (Scrob et al., 2022; El Hosry et al., 2025; Zhang et al., 2022; Lund & Ray, 2017; Lund & Ray, 2017).

Conclusion

Sugar concentration significantly affected the microbiological stability, physicochemical properties, and sensory characteristics of soursop jam during room-temperature storage. The 60% sugar concentration provided the most balanced product quality in terms of microbiological stability, moisture content, vitamin C retention, and sensory acceptance. The novelty of this study lies in the integration of microbiological and physicochemical parameters using a critical limit and risk-based assessment approach to explain the biological failure phase of local fruit-based jam products. Based on the observed mold and yeast growth, the shelf life of soursop jam is recommended not to exceed one week at room temperature. This study was limited to room-temperature storage without evaluating packaging

systems or natural preservatives. Future studies are recommended to investigate packaging technology, preservation methods, and storage conditions to improve shelf-life stability.

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Author Contributions

Conceptualization, R. I. M. B. and J. J. S. D.; methodology, R. I. M. B.; validation, R. I. M. B., A. P. N., and M. R. M.; formal analysis, R. I. M. B.; investigation, R. I. M. B., A. P. N., and M. R. M.; resources, R. I. M. B.; data curation, R. I. M. B.; writing—original draft preparation, R. I. M. B.; writing—review and editing, J. J. S. D.; visualization, R. I. M. B.; supervision, J. J. S. D.; project administration, R. I. M. B.; funding acquisition, R. I. M. B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

- Almaghlouth, B. J., Alqahtani, N. K., Alnabbat, K. I., Mohamed, H. A., Alnemr, T. M., & Habib, H. M. (2023). Valorization of Second-Grade Date Fruit Byproducts and Nonstandard Sweet Potato Tubers to Produce Novel Biofortified Functional Jam. *Foods*, 12(9). <https://doi.org/10.3390/FOODS12091906>
- AOAC. (2019). *Official Methods of Analysis of the Association of Official Analytical Chemists Official Methods of Analysis of AOAC International. 21st Edition*, AOAC, Washington DC. Retrieved from <https://www.scirp.org/reference/referencespapers?referenceid=2939092>
- Arsyad, M. (2018). Pengaruh Konsentrasi Gula Terhadap Pembuatan Selai Kelapa Muda (*Cocos nucifera* L). *Gorontalo Agriculture Technology Journal*, 1(2), 35–45. <https://doi.org/10.32662/GATJ.V1I2.424>
- Badan Standardisasi Nasional (BSN). (2008). *SNI 3746:2008 Selai Buah*. Retrieved from

- <https://pesta.bsn.go.id/produk/detail/7438-sni37462008>
- Banaś, A., Korus, A., & Tabaszewska, M. (2018). Quality assessment of low-sugar jams enriched with plant raw materials exhibiting health-promoting properties. *Journal of Food Science and Technology*, 55(1), 408–417. <https://doi.org/10.1007/S13197-017-2952-6>
- Belitz, H. D., Grosch, W., & Schieberle, P. (2009). Food chemistry. In *Food Chemistry*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-540-69934-7>
- Bengi, K. S., Sodri, A., & Martono, D. N. (2025). Analysis of Raw Material Potential Based on Leading Commodities for Sustainable Industrial Development in East Java. *Jurnal Penelitian Pendidikan IPA*, 11(12), 102–107. <https://doi.org/10.29303/JPPIPA.V11I12.13421>
- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing: JRN*, 25(8), 652–661. <https://doi.org/10.1177/1744987120927206>
- Duncan, D. B. (1955). Multiple Range and Multiple F Tests. *Biometrics*, 11(1), 1. <https://doi.org/10.2307/3001478>
- El Hosry, L., Elias, V., Chamoun, V., Halawi, M., Cayot, P., Nehme, A., & Bou-Maroun, E. (2025). Maillard Reaction: Mechanism, Influencing Parameters, Advantages, Disadvantages, and Food Industrial Applications: A Review. *Foods*, 14(11). <https://doi.org/10.3390/foods14111881>
- Giannakourou, M. C., & Taoukis, P. S. (2021). Effect of Alternative Preservation Steps and Storage on Vitamin C Stability in Fruit and Vegetable Products: Critical Review and Kinetic Modelling Approaches. *Foods*, 10(11). <https://doi.org/10.3390/foods10112630>
- Haryanto, B. (2018). Pengaruh penambahan gula terhadap karakteristik bubuk instan daun sirsak (*annona muricata* l.) Dengan metode kristalisasi. *Jurnal Penelitian Pascapanen Pertanian*, 14(3), 163. <https://doi.org/10.21082/JPASCA.V14N3.2017.163-170>
- ISO 4833-1. (2013). *Microbiology of the food chain – Horizontal method for the enumeration of microorganisms – Part 1: Colony count at 30 °C by the pour plate technique*. Retrieved from <https://www.iso.org/standard/53728.html>
- Jannah, A. A., Suryani, D., & Sukesi, T. W. (2023). Determinants of Food Safety Practices among Mothers of Toddlers in Gedongkiwo Village, Mantrijeron, Yogyakarta. *Jurnal Penelitian Pendidikan IPA*, 9(SpecialIssue), 324–331. <https://doi.org/10.29303/jppipa.v9iSpecialIssue.6161>
- Jha, P. K., Hanin, A., Tiwari, B. K., & Dallagi, H. (2026). Microbial safety in cold-preserved foods: risks, regulatory gaps, and mitigation strategies. *Food Control*, 182, 111869. <https://doi.org/10.1016/j.foodcont.2025.111869>
- Kawai, K., Toh, M., & Hagura, Y. (2014). Effect of sugar composition on the water sorption and softening properties of cookie. *Food Chemistry*, 145, 772–776. <https://doi.org/10.1016/j.foodchem.2013.08.127>
- Kubela, L., Moniharapon, E., & Tuhumury, H. C. D. (2023). Pengaruh Konsentrasi Gula Terhadap Karakteristik Kimia Dan Organoleptik Permen Jelly Buah Tomi-Tomi (*Flacourtia inermis*, Roxb). *Jurnal Sains Dan Teknologi Pangan*, 8(1). <https://doi.org/10.33772/JSTP.V8I1.29963>
- Lalujan, L. E., Putri, A. C., Langi, T. M., & Koapaha, T. (2025). The Effect of Mixing Rind of Watermelon (*Citrullus Lanatus*) and Kweni Mango (*Mangifera Odorata* Griff.) on the Quality of Slice Jam. *Jurnal Penelitian Pendidikan IPA*, 11(11), 26–34. <https://doi.org/10.29303/JPPIPA.V11I11.12052>
- Lubis, N., Damayanti, R., & Wardani, S. (2025). Antimicrobial Activity of Eco-enzymes with Various Dilutions As A Natural Disinfectant. *Jurnal Penelitian Pendidikan IPA*, 11(5), 506–513. <https://doi.org/10.29303/JPPIPA.V11I5.11052>
- Lund, M. N., & Ray, C. A. (2017). Control of Maillard Reactions in Foods: Strategies and Chemical Mechanisms. *Journal of Agricultural and Food Chemistry*, 65(23), 4537–4552. <https://doi.org/10.1021/acs.jafc.7b00882>
- Mao, Y., Tian, S., Qin, Y., & Chen, S. (2022). Sensory sweetness and sourness interactive response of sucrose-citric acid mixture based on synergy and antagonism. *Npj Science of Food*, 6(1). <https://doi.org/10.1038/S41538-022-00148-0>
- Meilgaard, M. C., Civille, G. V., & Carr. (2015). *Sensory Evaluation Techniques*. <https://doi.org/10.1201/B19493>
- Montgomery, D. C. (2017). *Design and Analysis of Experiments*. John Wiley & Sons.
- Mukminah, N., Azzahra, H., & Fathurohman, F. (2022). Pengaruh Konsentrasi Gula Terhadap Karakteristik Kimia dan Organoleptik Selai Carica (*Carica pubescens* l.). *Edufortech*, 7(2), 147–155. <https://doi.org/10.17509/edufortech.v7i2.51335>
- Nistor, O. V., Bolea, C. A., Andronoiu, D. G., Cotârlet, M., & Stanciuc, N. (2021). Attempts for developing novel sugar-based and sugar-free sea buckthorn marmalades. *Molecules*, 26(11). <https://doi.org/10.3390/MOLECULES26113073>
- Pawar, S. V., Saldinger, S. S., & Shemesh, M. (2026). Postbiotics for improving food quality and safety:

- From mechanistic insights to industrial applications. *LWT*, 241(11), 119066. <https://doi.org/10.1016/j.lwt.2026.119066>
- Picauly, P., Marshadu, M. J., Auratu, B., Andries, Y., Rumahrenu, M. J., Siatam, L., Erubun, B., Hamzah, W., & Wailisa, A. (2025). Pengaruh Konsentrasi Gula Terhadap Karakteristik Fisikokimia dan Organoleptik Marmalade Pisang Tongka Langit. *Jurnal Teknologi Pangan Dan Industri Perkebunan (LIPIDA)*, 5(2), 102-108. <https://doi.org/10.58466/LIPIDA.V5I2.1903>
- Quitral, V., Valdés, J., Umaña, V., Gallardo, N., Alcaino, M. J., Araya, C., & Flores, M. (2019). The role of non-caloric sweeteners in sensory characteristics of pastry products. *Foods*, 8(8). <https://doi.org/10.3390/FOODS8080329>
- Rababah, T. M., Al-U'Datt, M., Al-Mahasneh, M., Yang, W., Feng, H., Ereifej, K., Kilani, I., & Ishmais, M. A. (2014). Effect of Jam processing and storage on phytochemicals and physiochemical properties of cherry at different temperatures. *Journal of Food Processing and Preservation*, 38(1), 247-254. <https://doi.org/10.1111/j.1745-4549.2012.00770.x>
- Rahayu, W. E., Mukminah, N., & Aprilliani, F. (2026). Chemical and Organoleptic Characteristics of Pineapple Jam Production with Varying Sugar and Pectin Concentrations as Mochi Filling. *Jurnal Penelitian Pendidikan IPA*, 12(2), 655-661. <https://doi.org/10.29303/JPPIPA.V12I2.14213>
- Rana, M. S., Yeasmin, F., Khan, M. J., & Riad, M. H. (2021). Evaluation of quality characteristics and storage stability of mixed fruit jam. *Food Research*, 5(1), 225-231. [https://doi.org/10.26656/FR.2017.5\(1\).365](https://doi.org/10.26656/FR.2017.5(1).365)
- Ridawati, Alsuhendra, & Ramadani, M. I. (2023). Sanitation Knowledge and Hygiene Practices: An Evaluation of Indonesian Online Food SMEs Based on National Food Safety Guidelines. *Jurnal Penelitian Pendidikan IPA*, 9(12), 11641-11647. <https://doi.org/10.29303/JPPIPA.V9I12.5622>
- Rochmah, M. M., Ferdiansyah, M. K., Nurdyansyah, F., Muliani, R., Ujianti, D., & Pangan, J. T. (2019). Pengaruh Penambahan Hidrokoloid Dan Konsentrasi Sukrosa Terhadap Karakteristik Fisik Dan Organoleptik Selai Lembaran Pepaya (Carica Papaya L.). *Jurnal Pangan Dan Agroindustri*, 7(4), 42-52. <https://doi.org/10.21776/UB.JPA.2019.007.04.5>
- Rosadalima, T., Awi, E., Prasanto Bimantio, M., & Hastuti, S. (2022). Inovasi Produk Selai Salak (Salacca Zalacca) Dengan Penambahan Daun Kelor (Moringa Oleifera) Sebagai Sumber Kalsium. *Jurnal Teknologi Pangan Dan Gizi (Journal of Food Technology and Nutrition)*, 21(2), 133-143. <https://doi.org/10.33508/JTPG.V21I2.4166>
- Roza, M., Sari, M., Nurhasnah, Meria, A., Herman, M., & Meriko, L. (2025). Food Safety and Community Behavior Toward Traditional Foods in West Sumatra Tourist Destinations: A Chemical, Biological, and Science Education Perspective. *Jurnal Penelitian Pendidikan IPA*, 11(11), 165-174. <https://doi.org/10.29303/JPPIPA.V11I11.12383>
- Scrob, T., Varodi, S. M., Vintilă, G. A., Casoni, D., & Cimpoiu, C. (2022). Estimation of degradation kinetics of bioactive compounds in several lingonberry jams as affected by different sweeteners and storage conditions. *Food Chemistry: X*, 16, 100471. <https://doi.org/10.1016/j.fochx.2022.100471>
- Simamora, C., Ayu Kadek Diah Puspawati, G., Agung Istri Sri Wiadnyani, A., Studi Teknologi Pangan, P., & Teknologi Pertanian, F. (2026). Karakteristik Fisikokimia, Sensori, dan Potensi Fungsional Flakes dari Tepung Komposit Mocaf dan Kelor dengan Penambahan Tepung Pisang Kepok. *Jurnal Teknologi Dan Industri Pangan*, 37(1), 11-24. <https://doi.org/10.6066/JTIP.2026.37.1.11>
- SNI 3746. (2008). *Selai Teknologi & Rekayasa*. Retrieved from <https://www.scribd.com/doc/144557005/SNI-3746-2008-Selai>
- Susilowati, A., Aspiyanto, A., Dinoto, A., & Lotulunga, P. D. (2012). Pemisahan Eksopolisakarida (Eps) Sebagai Metabolit Bakteri Usus untuk Aditif Makanan dalam Biomassa Pati Sagu (Metroxylon sp.) dan Glukosa melalui Sistem Mikrofiltrasi Sel Berpengaduk (Separation of Exopolysaccharides (Eps) As Colon Bacteria Metabolismf. *Jurnal Pangan*, 21(4), 375-385. <https://doi.org/10.33964/JP.V21I4.203>
- Syamsiar, Kadekoh, I., Marhani, Maemunah, Rozali, R., Zainuddin, R., Salam, N., & Humaerah, N. (2025). Sugar and Fiber Content in Sorghum Seeds (Sorghum bicolor (L.) Moench) From the Application of Rice Husk Biochar and Liquid Cow Urine Organic Fertilizer. *Jurnal Penelitian Pendidikan IPA*, 11(7), 467-474. <https://doi.org/10.29303/JPPIPA.V11I7.11550>
- Taiwo, O. R., Onyeaka, H., Oladipo, E. K., Oloke, J. K., & Chukwugozie, D. C. (2024). Advancements in Predictive Microbiology: Integrating New Technologies for Efficient Food Safety Models. *International Journal of Microbiology*, 6612162. <https://doi.org/10.1155/2024/6612162>
- Vermelho, A. B., Moreira, J. V., Junior, A. N., da Silva, C. R., Cardoso, V. da S., & Akamine, I. T. (2024). Microbial Preservation and Contamination Control in the Baking Industry. *Fermentation*, 10(5). <https://doi.org/10.3390/fermentation10050231>

- Zaitun. (2024). Culinary Hygiene and Sanitation: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, 10(8), 598–605. <https://doi.org/10.29303/JPPIPA.V10I8.8307>
- Zeng, X., Meng, J., Zhang, W., He, L., Deng, L., & Ye, C. (2021). Changes in the microbiological, physicochemical properties of Chinese traditional fermented Suan rou at ripening fermentation. *Food Science and Nutrition*, 9(11), 5899–5913. <https://doi.org/10.1002/FSN3.2095>
- Zhang, L., Zhang, J., & Guo, J. (2024). Relationships Between Organic Acid Metabolism and the Accumulation of Sugars and Calcium in Fruits of *Cerasus humilis* During Different Development Stages. *Plants*, 13(21), 3053. <https://doi.org/10.3390/plants13213053>
- Zhang, R. L., Zhang, M. M., Pu, Y. F., & Zhu, L. X. (2022). Evolution of nonenzymatic browning during the simulated Msalais-production process in models of grape juice. *Food Science & Nutrition*, 10(7), 2132. <https://doi.org/10.1002/fsn3.2829>
- Žlabur, J. Š., Mikulec, N., Doždor, L., Duralija, B., Galić, A., & Voća, S. (2021). Preservation of Biologically Active Compounds and Nutritional Potential of Quick-Frozen Berry Fruits of the Genus *Rubus*. *Processes*, 9(11). <https://doi.org/10.3390/pr9111940>