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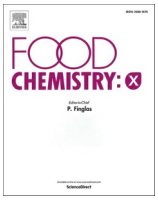

Assessment of changes in product quality and antioxidant activity of dried soursop (*Annona muricata* L.) during product storage

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ABSTRACT

Innovations for product preservation have attracted interest as they may increase the shelf-life of items when stored properly. In this study, the effects of various storage conditions, including four types of packaging (paper packaging, paper combined PE packaging, aluminum combined PE packaging, and plastic jar packaging) and temperatures (5, 15, 30, and 45 °C) on the quality of dried soursop were evaluated. The results demonstrated that the combination of plastic jar packaging and a storage temperature of 15 °C retained a significant portion of the initial total ascorbic acid content, total polyphenol content, and total flavonoid content. After four weeks of storage, the dried soursop preserve packaged in a plastic jar and stored at 15 °C exhibited a moisture content of 22.977 ± 0.093 %, total ascorbic acid content of 9.7 ± 0.46 mg/100gDW, total polyphenol content of 8.12 ± 0.06 mgGAE/gDW, total flavonoid content of 0.18 ± 0.02 mgQE/gDW, DPPH and ABTS scavenging activity of 0.69 ± 0.01 mgAA/gDW and 0.82 ± 0.01 mgAA/gDW, respectively. Moreover, the product meets the requirements of decision 46/2007/QD-BYT regulating the limits on biological and chemical contamination in food. The study offers valuable insights for the food industry in optimizing packaging and storage conditions to ensure the storage of quality and health-beneficial properties of this product.

Introduction

Soursop (*Annona muricata* L.) is a widely consumed fruit harvested from a tree grown in tropical and sub-tropical regions of Central America, South America, and Southeast Asia (Pineda-Ramírez et al., 2020). In Vietnam, soursop trees are mainly cultivated in the South and Central regions, particularly in Tien Giang province. Various human ailments are prevented and treated using soursop fruit, which has a strong flavor and high nutritional content (Patel & Patel, 2016; Gavamukulya et al., 2017). It contains over 20–35 mg of vitamin C per 100 g of soursop, as well as carbohydrates and bioactive compounds such as acetogenins, alkaloids, and phenolic compounds such as quercetin and gallic acid, which exhibit high antioxidant and biological activities (Khăn et al., 2007). The fruit's abundant vitamin and mineral content further contributes to its potential health benefits, bolstering the immune and digestive systems (Nguyễn et al., 2020).

Soursop fruit is harvested when almost ripe and must be used within 3–4 days, as it is highly perishable. To preserve and enhance its values, dried soursop has been developed for storage and improved food quality. The suitable drying methods must be selected for different raw materials to minimize the loss of sensory attributes and nutritional content. Currently, several drying techniques are available, with different advantages and disadvantages. These techniques include freeze-drying, radiation drying, convection drying, and spray-drying. The convection drying technique has been widely used in the past for a variety of fruits and vegetables such as apples (Velić et al., 2004), mushrooms (Pal & Chakraverty, 1997), green olives (Demir et al., 2007), and root vegetables (Pabis, 1999). However, conventional convection drying exposes the material directly to hot air at high temperatures, potentially compromising the product quality and nutrient

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retention (Samlanexay & Phạm, 2018). Therefore, the heat pump drying technique was applied to produce the dried soursop in this study. Unlike conventional drying techniques, this technique utilizes low-temperature drying and atmospheric pressure conditions. This approach is selected to minimize the adverse effects on the product's quality, while preserving its color and maximizing the nutritional value (Mẫn et al., 2011). The efficacy of this approach has been demonstrated in a study by Nguyen et al., 2023 which optimized the response surface methodology for producing dried soursop.

However, the changes in color and nutritional content remain major concerns in the storage process, as they affect the marketing and economic values of the product. It is common knowledge that the quality of most food items would eventually be lost over time. Additionally, packaging materials and storage temperature have been found to significantly affect the quality and sensory characteristics of dried fruits. It was determined that dried fig samples stored at 18 °C maintained their color characteristics, while the samples stored at higher temperature (28 °C) darkened rapidly (Cárcel et al., 2010). Coşkun et al., (2013) also reported that in order to protect the golden-yellow color of dried apricots during storage, the storage temperature should be prioritized below 20 °C. Another study by Liuqing et al., (2018) investigated the storage conditions for freeze-dried *A. bisporus* mushroom slices, confirming the importance of temperature and humidity in preserving product microstructure and sensory attributes. Moreover, effective packaging has proven crucial in maintaining the quality of dried fruits. A study conducted in dried apricots found that the carotenoids were protected from degradation and loss through vacuum-package (Deng et al., 2022). Additionally, it was discovered that the nitrogen packing minimized ascorbic acid loss in dried mango powder. According to Caparino et al., (2017), the ascorbic acid content was reduced by 31.8% when held at 22 °C for a year by nitrogen packing instead of 41.7% by air packaging. Yao et al., (2020), also reported that dried mango slices stored at 25 °C with modified atmosphere packaging (MAP1: packed with 100% CO_2) retained the highest ascorbic acid content of 61.21 %, with better quality and minimal nutrient losses.

Despite extensive research on processing techniques for dried soursop storage, little has been known about the quality degradation during storage. Most existing studies have focused on the processing techniques rather than the storage phase. Considering these limitations, the present study aims to assess the effects of temperature (5–45 °C) and packaging materials (e.g. paper packaging, paper combined PE packaging, aluminum combined PE packaging, and plastic jar packaging) on the physicochemical characteristics, chemical composition, and biological activity of dried soursop storage over time.

Materials and methods

Materials preparation

Soursop fruits (*Annona muricata L.*) were harvested in Tan Phu Dong district, Tien Giang province, Vietnam(10.4493° N, 106.3421° E). The fruits were harvested at 12 weeks of age after the fruit-bearing stage. After harvesting, the soursop fruits were transported to the laboratory within 8 h. All the collected soursop fruit is at the technical ripeness level with evenly opened outer shell spines and Brix level of 13-15°Bx. They were stored under cool temperature conditions (4–8 °C) for further analysis.

The heat pump drying technique was applied to produce dried soursop in this study. Heat pump drying uses dry air with about 10–30% of humidity at 30–60 ℃. In other words, the heat pump drying process is carried out under atmospheric pressure conditions. It can be seen that the temperature of the heat pump drying environment is relatively low because it only ranges from 30 to 60 ℃, so the product quality seems to be less affected, the color and nutritional value of the products are retained at a maximum level. After sorting, the fruits were peeled, removed seeds and shaped to a thickness of 1 ± 0.2 cm. Subsequently, the fruit pulp was blanched by immersion in water at 70 ℃ for 2 min and rapidly cooled with ice water. Then, it was filtrated with a 60° Brix syrup solution under vacuum for 45 min at a pressure of 40 cmHg (syrup composition ratio: 1:3 w/w). Next, the soursop was cooled using a water solution containing 0.01% sodium benzoate. Finally, soursop fruit pulp after soaking is spread evenly on a stainless steel tray with mesh holes < 1 cm^2 was dried in a chamber under air convection (50 Hz) at a temperature of 35 ℃ until reaching a final moisture content below 15 ± 2 g water/100gDW and was then proceeded to product packaging.

Fig. 1. Types of packaging used in the experiment: A) Kraft paper bag; B) bag of paper combined with polyethylene (PE); C) bag of aluminum combined with PE; D) jar of polyethylene terephthalate (PET).

Packaging and storage

Several packaging options are available (Fig. 1):

P: Bag of kraft paper (16.5 cm × 21 cm; 120 μm thickness).

P/PE: Bag (15 cm × 22 cm) of paper combined with polyethylene (PE) (170 μm thickness).

Al/PE: Bag (15 cm × 22 cm) of aluminum combined with PE (200 μm thickness).

PET: Jar (500 mL; 9 cm × 5 cm) of polyethylene terephthalate (PET) with 400 μm thickness; lid of aluminum.

Packaged in bags: The dried soursop weighing 50 g was placed into a zipper bag and then sealed by heat sealing (SF-400, China). Packaged in the plastic jar: The dried soursop weighing 50 g was placed into a plastic jar and then filled with using an aluminum foil sealing machine (seal 500A, China).

Experimental setup

The following experiments were performed in triplicate.

Experiment 1: An amount of 50 g of the dried soursop obtained was packed into each packaging detailed in section 2.2. The samples were placed at room temperature for a period of 4 weeks. The color, moisture content, TPC, TFC, DPPH, ABTS, total aerobic microorganisms, total yeast, and mold were evaluated at weeks 1, 2, 3, and 4. These experiments were repeated three times.

Experiment 2: The packaging material selected from Experiment 1 was used, weighing 50 g. Different temperatures (5 °C, 15 °C, 30 °C, 45 °C) were employed for a storage period of 4 weeks in a chamber (Multi Room Incubator SHIC, Han Beak Scientifi Co.). The color, moisture content, TAA (total ascorbic acid), TPC (total polyphenol content), TFC (total flavonoid content), determination of scavenging activity by DPPH and ABTS, total aerobic microorganisms, total yeast, and mold were evaluated at weeks 1, 2, 3, and 4. These experiments were repeated three times.

Chemicals

The Folin-Ciocalteu reagent (FCR), gallic acid, 2,2-dephenyl-1-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and 2,6-dichlorophenolindophenol (DCPIP) were purchased from Sigma-Aldrich Chemie, Co. Ltd. (Missouri, USA). Other chemicals such as distilled water (pH ranging from 6.5 to 8), ethanol (96 % purity), Na_2CO_3 (99.5 % purity), L-ascorbic acid (99.7 % purity), $AlCl_3$ (97 % purity), and CH_3COOK (98.14 % purity) were sourced from

Xilong, China.

Analytical methods

Determination of color and moisture content

$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$The Chromameter Konica Minolta CR-400 (Tokyo Japan) was used to measure the color (CIE Lab* color space). The results were displayed as numerical values through L* (ranging from 0 to 100), a* (from green to red), and b* (from blue to yellow) values. The measured L*, a*, and b* values were used to calculate the color difference (Delta E, ΔE) and browning index (BI) to identify the sample's color departure from the original sample (Alagöz et al., 2015):

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

$$BI = \frac{100 \times (x - 0.31)}{0.17} \quad (2)$$

$$x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$$

The moisture content that indicated the loss during the drying procedure was measured by De Knegt & Van Den Brink, (1998). In brief, 5 g of samples were added after the drying dish had been weighed, and both the dish and the sample were then weighed. The total weight was recorded. Then, the sample was transferred to the drying oven at 105 °C until a constant weight was achieved, and the loss in weight represented the water content. The moisture content was calculated using the following formula:

$$A = \frac{m_1 - m_2}{m_1} \times 100\%$$

with m_1: weight before drying (g); m_2: weight after drying (g).

Determination of total ascorbic acid content (TAA)

The total ascorbic acid (TAA) content in the samples was determined using the DCPIP titration method described by Manas, (2014), as previously described by Dao et al., (2022). 1 g of sample was extracted with 100 mL of distilled water. After that, 10 mL of the sample solution was added to 1 mL of 0.04% HCl, and DCPIP was used to titrate the mixture. The analytical sample was diluted with 0.1 g ascorbic acid up to 100 mL in the same manner described above for the control sample. A colorless solution was titrated to a pale pink one within 30 s during three separate experiments. A record was made of the DCPIP solution's volume. TAA is calculated by Equation (4) and expressed in mg per gram of dry matter (mg /g dry matter).

$$TAA(mg/g) = \frac{(\boldsymbol{V_0} - \mathbf{0.05}) \times \boldsymbol{V_1}}{\mathbf{10} \times \boldsymbol{m_m}} \times \frac{\mathbf{m}}{\boldsymbol{V_C} - \mathbf{0.05}} \quad (4)$$

with, V_0: sample standard DCPIP volume (mL); V_C: ascorbic acid standard DCPIP volume (mL); V_1: rated flask volume (mL); m_C: weight of pounded ascorbic acid (g); m_m: weight of the weighed sample (g).

Determination of total polyphenol content (TPC)

Using gallic acid as a reference, the Folin-Ciocalteu colorimetric technique was used to determine the total polyphenol content (TPC), (Vuong et al., 2013; Thao et al., 2023). A total of 50 mL of 100% ethanol was homogenized with 5 g of dried soursop multiple times. The extract (0.1 mL) was mixed with 0.5 mL of 10% Folin-Ciocalteu reagent and 7.5% Na_2CO_3 solution in a dark test tube. The test tubes were incubated for 60 min in the dark. After incubation, a UV–Vis spectrophotometer (UV-5100, Matash, China) was used to detect the samples' absorbance at 765 nm. TPC is calculated by Equation 5 and expressed in milligrams of gallic acid equivalent per gram of dry matter (mgGAE/gDW).

$$TPC = \frac{C_x \times n \times V \times 100}{m \times (100 - X)} \times 10^{-3}$$

In which, TPC: Total phenolic content (mgGAE/gDW); C_x: Gallic acid concentration determined from baseline (μg/mL); n: Dilution from root extract; V: Volume of root extract (mL); X: Sample moisture (%); m: Sample mass (g).

Determination of total flavonoid content (TFC)

According to Mahboubi et al., (2013), the total flavonoid content (TFC) was calculated using technique where $AlCl_3$ forms, $AlCl_3$ forms an orange-brown complex with flavonoids. 5 g of soursop dried was pureed several times with 50 mL of absolute ethanol. 0.1 mL of a 10% $AlCl_3$ solution was added to a test tube after the extract (0.5 mL) had been added. Additionally, the test tube was gradually filled with 4.3 mL of pure ethanol and 0.1 mL of 1 M CH_3COOK solution, then allowed to react at room temperature for 30 min. The solution's optical absorbance was measured at a wavelength of 415 nm by using UV–Vis spectrophotometer (UV-5100, Matash, China). Quercetin was used as the standard. The TFC is expressed in milligrams of quercetin equivalents per gram of dry matter (mgQE/ gDW) using Equation 6 below:

$$TFC = \frac{C_x \times n \times V \times 100}{m \times (100 - X)} \times 10^{-3}$$

In which TFC: Total flavonoid content (mgGAE/gDW); C_x: Quercetin concentration determined from baseline (μg/mL); n: Dilution from root extract; V: Volume of root extract (mL); X: Sample moisture (%); m: Sample mass (g).

Determination of scavenging activity by DPPH

The free radical scavenging activity of the samples were determined using the DPPH method (Tran et al., 2022) (Gulcin, 2023) (Gulcin & Alwasel, 2023). 5 g of dried soursop was pureed several times with 50 mL of absolute ethanol. 0.5 mL of solution sample was added with 1.5 mL of DPPH solution (OD 517 nm = 1.1 ± 0.02). The mixture was incubated for 30 min in the dark. The mixture's optical absorbance was measured by using UV–Vis spectrophotometer (UV-5100, Matash, China) at at a wavelength of 517 nm. The reference substance was ascorbic acid DPPH free radical scavenging capacity is expressed in milligrams of ascorbic acid equivalents per gram of dry matter (mgAA/ gDW).

Determination of scavenging activity by ABTS

The antioxidant activity of dried soursop was tested by the ABTS method, based on the description of V. T. Nguyen et al., (2020) and Karagecili et al., (2023). First, 10 mL of 2.6 nM $K_2S_2O_8$ was added to 10 mL of 7.4 nM ABTS solution to stabilize the solution for 24 h. 5 g of dried soursop was pureed several times with 50 mL of absolute ethanol. Next, 1.5 mL of ABTS solution (OD 734 nm = 1.1 ± 0.02) was added to the 0.5 mL solution sample. The mixture was incubated in the dark for 30 min. The mixture's optical absorbance was measured at a wavelength of 734 nm by using UV–Vis spectrophotometer (UV-5100, Matash, China). Ascorbic acid was used as the standard. The amount of ascorbic acid equivalent per gram of dry matter (mgAA/DW) used to measure ABTS free radical scavenging capability.

Quantification of total aerobic microorganisms and the total number of yeasts and molds

The quantitative method of total aerobic microorganisms is carried out according to TCVN 6507–1:2005 (Microbiology of food and animal feeding stuffs - Preparation of test samples, initial suspension and decimal dilutions for microbiological examination - Part 1: General rules for the preparation of the initial suspension and decimal dilutions), TCVN 6404:2008 (Microbiology of food and animal feeding stuffs - General requirements and guidance for microbiological examinations), and

Table 1
Color and moisture content of dried soursop preserved by four types of packaging.

Packaging	Time (week)	L*	ΔE	BI	Moisture (%)
	0	79.65 ± 1.77	0	19.83 ± 0.96	15.159 ± 0.389
P	1	63.07 ± 5.34^{Ac}	17.82 ± 4.72^{Ca}	34.35 ± 2.18^{Ba}	20.852 ± 0.397^{Ca}
	2	61.32 ± 4.29^{Ab}	18.78 ± 3.72^{Cb}	37.38 ± 2.56^{Bab}	22.363 ± 0.577^{Cb}
	3	61.33 ± 1.98^{Aab}	18.49 ± 1.95^{Cbc}	37.6 ± 0.89^{Bab}	24.297 ± 0.437^{Cc}
	4	58.97 ± 2.01^{Aa}	21.61 ± 1.82^{Cc}	41.24 ± 5.86^{Bb}	25.824 ± 0.318^{Cd}
Al/PE	1	65.06 ± 5.18^{Bc}	15.14 ± 1.75^{Ba}	28.94 ± 8.7^{Aa}	17.619 ± 0.107^{Aa}
	2	63.77 ± 2.45^{Bb}	16.61 ± 1.1^{Bb}	33.38 ± 6.64^{Aab}	21.294 ± 0.225^{Ab}
	3	62.18 ± 1.37^{Bab}	18.01 ± 0.94^{Bbc}	34.7 ± 0.95^{Aab}	23.645 ± 0.493^{Ac}
	4	61.36 ± 2.38^{Ba}	18.93 ± 1.54^{Bc}	35.52 ± 3.93^{Ab}	24.712 ± 0.505^{Ad}
P/PE	1	69.24 ± 5.01^{BCc}	12.28 ± 1.6^{ABa}	30.8 ± 2.62^{Aa}	18.254 ± 0.429^{Ba}
	2	64.51 ± 1.81^{BCb}	15.84 ± 0.74^{ABb}	33.53 ± 2.68^{Aab}	21.792 ± 0.32^{Bb}
	3	63.12 ± 1.32^{BCab}	17.05 ± 0.47^{ABbc}	34.43 ± 2.21^{Aab}	23.802 ± 0.5^{Bc}
	4	61.89 ± 2.54^{BCa}	18.36 ± 0.17^{ABc}	36.72 ± 5.1^{Ab}	25.523 ± 0.406^{Bd}
PET	1	70.07 ± 5.01^{Cc}	10.5 ± 4.01^{Aa}	29.68 ± 5.41^{Aa}	17.767 ± 0.478^{Aa}
	2	65.16 ± 2.71^{Cb}	15.95 ± 0.74^{Ab}	32.03 ± 1.62^{Aab}	21.266 ± 0.226^{Ab}
	3	64.72 ± 2.35^{Cab}	16.03 ± 1.52^{Abc}	33.72 ± 6.35^{Aab}	23.115 ± 0.497^{Ac}
	4	63.32 ± 3.51^{Ca}	17.38 ± 1.97^{Ac}	34.44 ± 4.68^{Ab}	24.086 ± 0.334^{Ad}

P_Paper; Al/PE_Aluminum combined PE; P/PE_Paper combined PE; PET_Plastic jar. $^{A-D}$: Values in the column with various capital letters, corresponding to various packing types, are significant at the $P < 0.05$ level. $^{a-e}$: The values in the lowercase lettered column are different, and the difference in storage time is significant at the $P < 0.05$ level.

TCVN 4884–1:2015 (Microbiology of the food chain - Horizontal method for the enumeration of microorganisms - Part 1: Colony count at 30 °C by the pour plate technique). The quantitative method for the total of yeasts and molds was carried out according to TCVN 8275–1,2:2012 (ISO 21527–1,2:2008), (Microbiology of food and animal feeding stuffs - Horizontal method for the enumeration of yeasts and moulds).

Data analysis

The data in this study was analyzed using Statgraphics Centurion XV (StatPoint Technologies, Inc, Ohio, USA) and Microsoft Excel 2019 (Washington, USA) and expressed as average values ± standard deviations (S.D.) of 3 replicates (n = 3). Differences between average values were carried out by analysis of variance and significance level was considered as $p < 0.05$.

Result and discussion

The effects of storage packaging types on physicochemical properties, chemical composition, and biological activity over time of dried soursop

The effects of storage packaging types on the color and moisture content of dried soursop products

Color was a significant quality factor since it affected customer acceptability in fruit and vegetable goods. Table 1 and Fig. 2 have shown that the color values of dried soursop were significantly affected by packaging type and storage time. As the storage time prolongs, the L* value of the samples gradually decreases in all four types of packaging. Among them, the decreased L* value revealed no statistically significant difference throughout the 4-week storage period between the packing types Al/PE and P/PE (61.362 and 61.892, respectively). However, packaging type P exhibited the lowest L* value after four weeks of storage (58.97 ± 2.01), indicating a faster decline compared to other packaging types, and the change was statistically significant ($p < 0.05$). Conversely, the packaging type PET exhibited the least variation with an L* value of 63.32 ± 3.51 after four weeks of storage. The ΔE value showed a distinct difference between packaging type P and other packaging types during the 4-week storage period. The ΔE value tended to increase over time. Specifically, packaging type P had the highest ΔE value after four weeks of storage (21.61 ± 1.82), followed by packaging type Al/PE (18.93 ± 1.54), P/PE (18.36 ± 0.17), and PET (17.38 ± 1.97). The browning index (BI) also increased over the storage time. After the first week, the BI value dramatically increased for all four packaging types. The results after four weeks of storage showed that packaging type P had the highest BI value (34.35 ± 2.18), followed by P/PE (30.8 ± 2.62), PET (29.68 ± 5.41), and Al/PE (28.94 ± 8.7). However, previous research has shown that variations in food's color are frequently caused by water activity, sugar content, temperature, and storage period, leading to non-enzymatic browning in the preserved food product (Tan et al., 2021); (Tripetch & Borompichaichartkul, 2019). The results from this study show that although dried soursop color properties may alter storage, these changes often follow consistent trends.

The food qualities, including texture, color, and nutritional value, are significantly influenced by moisture content (Miranda et al., 2014). The effects of packaging and storage time on moisture content of dried soursop is shown in Table 1. The moisture contents of the packaging types Al/PE (24.712 ± 0.505 %) and PET (24.086 ± 0.334%) after four weeks was not significantly different ($p < 0.05$). In contrast, significant differences in moisture content were observed for packaging types P and P/PE after four weeks (25.824 ± 0.318% and 25.523 ± 0.406 %, respectively) compared to packaging types Al/PE and PET. Overall, packaging type and storage time significantlty impacted on moisture content ($p < 0.05$). Moisture is released during dried fruit storage due to Maillard reactions and is exchanged with the environment through the packaging material (Mahdavi et al., 2010). On the other hand, oxygen permeability through the packaging is also an important factor affecting moisture content and shelf-life in various packaged foods. Previously, the impact of rapeseed oil on the oxygen barrier qualities of polymer packaging materials was investigated by Johansson & Leufvén, (1994). They discovered that amorphous PET continued to function as a great oxygen barrier for rapeseed oil even after 40 days of storage. As a result of the polymer's matrix swelling after 40 days in contact with rapeseed oil, PP and HDPE demonstrated an enhanced oxygen transfer rate (OTR). This partly explains the lower gas permeability of packaging types P and P/PE, leading to higher moisture absorption. The results indicate that packaging types PET and Al/PE exhibit better moisture uptake prevention than other packaging types for dried soursop.

The effects of storage packaging on TAA, TPC, TFC and antioxidant activity of dried soursop

TAA decreased significantly from the second week of storage (Fig. 3A). This can be explained by the fact that ascorbic acid is transformed into dehydroascorbic acid during oxidation processes (Aslam et al., 2019). Specifically, the initial TAA value was 17.8 ± 0.79 mg/100gDW. The highest reduction in TAA occurred after four weeks of storage. In particular, the TAA ranged from 15.6 ± 0.8 to 2.5 ± 0.78 mg/100gDW in packaging type P, 14.5 ± 0.81 to 2.53 ± 0.32 mg/

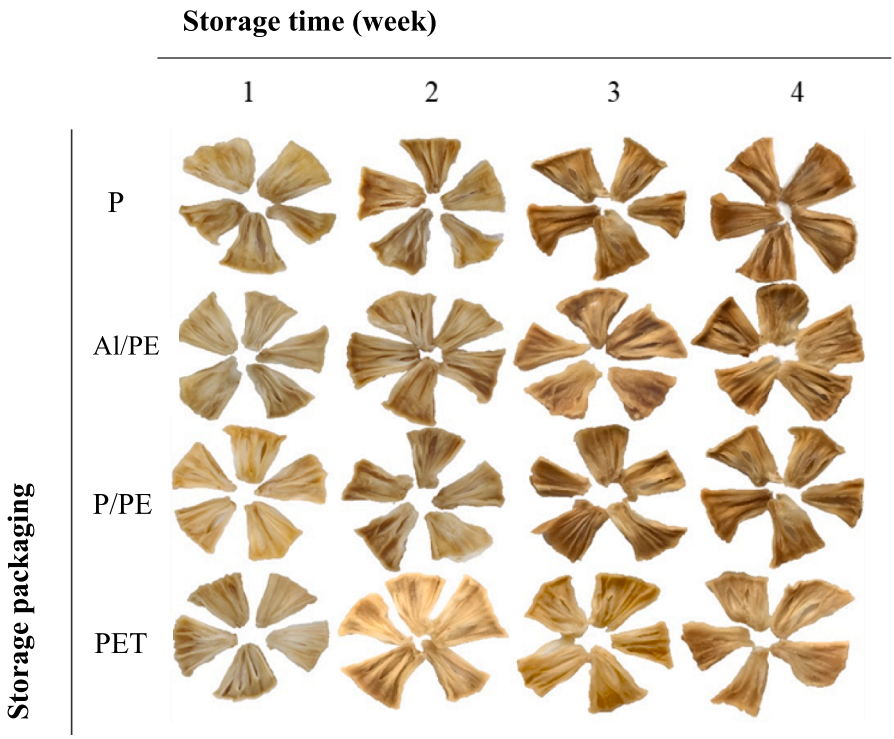

Fig. 2. Color change of soursop dried affected by packaging over time.

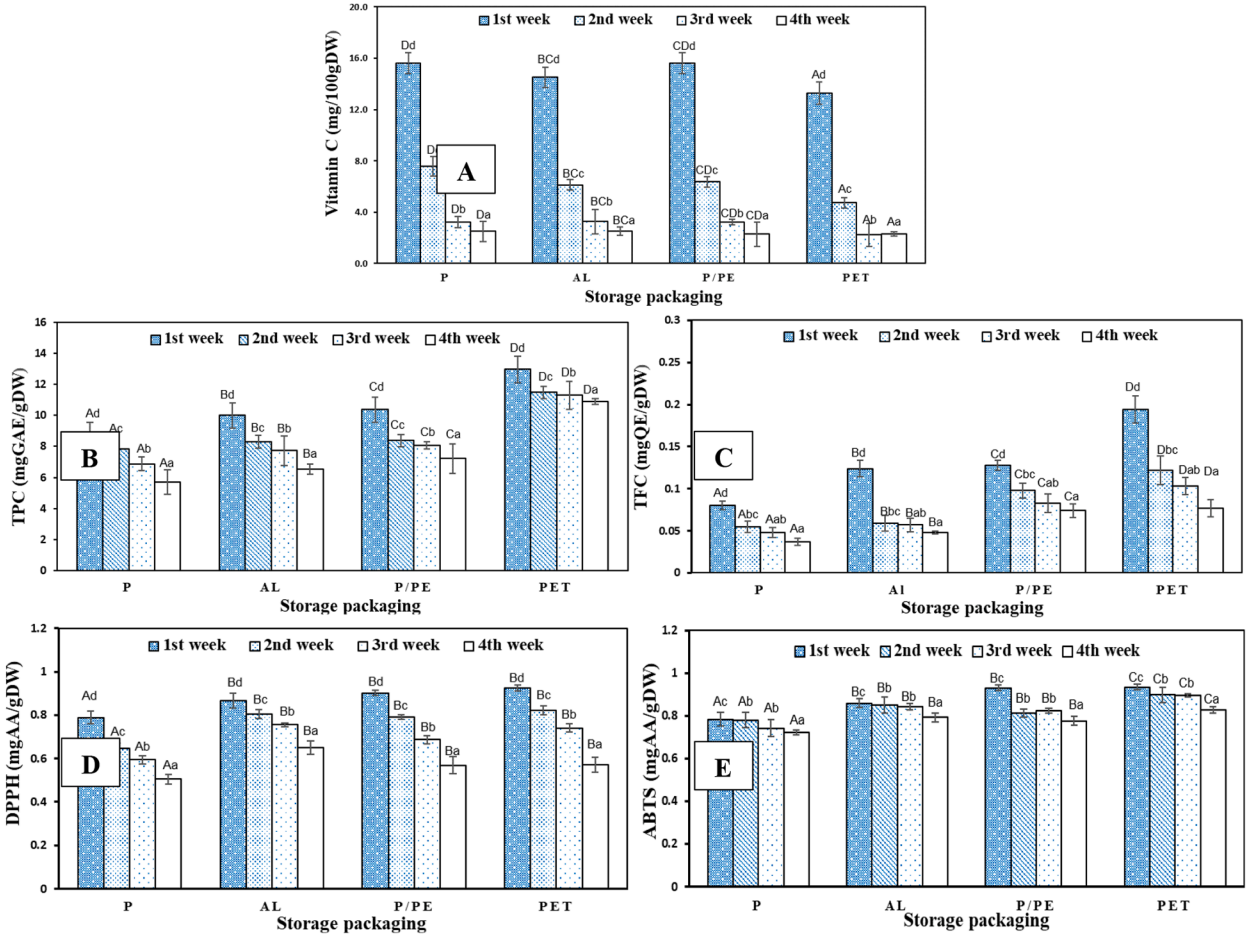

Fig. 3. Variation of TAA (A), TPC (B), TFC (C), DPPH (D), and ABTS (E) content of soursop dried affected by packaging-types during four weeks of storage.

Table 2
Microbiological test results.

Storage	Time (week)	Total aerobic microorganisms (CFU/g)	Total yeast mold (CFU/g)
P	1	2.2×10^3	U
	2	1.5×10^4	U
	3	1.7×10^4	1.4×10^2
	4	2.3×10^4	2.5×10^2
Al/PE	1	2.3×10^3	U
	2	4.6×10^3	U
	3	4.5×10^3	U
	4	5.4×10^3	10^2
P/PE	1	2.2×10^3	U
	2	4.5×10^3	U
	3	5.6×10^3	10^2
	4	6.5×10^3	10^2
PET	1	2.1×10^3	U
	2	2.5×10^3	U
	3	4.3×10^3	U
	4	5.6×10^3	U

P_Paper; Al/PE_Aluminum combined PE; P/PE_Paper combined PE; PET_Plastic jar; U_Undetectable.

100gDW in packaging type Al, 15.6 ± 0.81 to 2.3 ± 0.95 mg/100gDW in packaging type P/PE, and 13.3 ± 0.87 to2.3 ± 0.17 mg/100gDW in packaging type PET. Packaging types P and P/PE exhibit high gas permeability and lower thickness compared to the other packaging types, leading to increased light penetration and oxygen content inside the package, which may result in more significant loss of Vitamin C.

The variation of TPC in dried soursop over 4-week of storage using four types of packaging is shown in Fig. 3B. TPC decreases during storage mostly due to the oxidation of most polyphenolic compounds. Specifically, the initial TPC value as 14.28 ± 0.47 mgGAE/gDW. TPC was significantly reduced from 8.77 ± 0.04 mgGAE/gDW to 5.69 ± 0.09 mgGAE/gDW when packaged in type P after 4 weeks. This significant loss of TPC can be attributed to the higher permeability and evaporation capacity of packaging type P compared to the other packaging types. The TPC content in packaging type PET decreased from 12.96 ± 0.07 mgGAE/gDW in the first week to 10.89 ± 0.29 mgGAE/gDW in the fourth week, indicating the ability to retain polyphenols to a greater extent, as compared to other packaging types. This can be explained by the fact that sweet chemicals do not influence the PET's oxygen permeability, which continues to function as a reliable oxygen barrier (Van Willige et al., 2002). Additionally, its good thermal insulation properties and the prevention of air exposure and physical damage help preserve the product's structural integrity.

The variation of TFC according to packaging type and storage time of the dried soursop jam samples is shown in Fig. 3C. Specifically, the TFC content in the unpackaged samples was 0.27 ± 0.01 mgQE/mgDW. The sample's TFC in packaging type P decreased from 0.08 ± 0.05 to 0.04 mgQE/mgDW; the sample's TFC of packaging-type Al/PE exhibited decreased from 0.12 ± 0.01 to 0.05 mgQE/mgDW; the TFC ofP/PE reduced 0.13 ± 0.6 to 0.07 ± 0.01 mgQE/mgDW and the packaging type PET reduced from 0.19 ± 0.02 to 0.1 ± 0.02 mgQE/mgDW. Significant TFC reduction was observed in the samples preserved in packaging type P, partly due to the paper's high vaporation and moisture permeability. Consequently, it can potentially cause the loss of small bioactive compounds such as flavonoids through evaporation and interaction with the external environment. Prolonged storage with high humidity can lead to cell damage, altering and diminishing the activity of flavonoids. Additionally, over time, flavonoids may reduce the content and participate in browning reactions (Thu & Van Thiet, 2015) (Gülçin, 2012) (Karagecili et al., 2023).

The DPPH and ABTS free radical scavenging techniques were used to assess the antioxidant activity. After four weeks of storage, the antioxidant activity of the four types of packaging materials decreased in both analysis methods. Specifically, the initial DPPH content before packaging was 0.91 ± 0.03 mgAA/gDW. For packaging material P, the DPPH value decreased from week 1 to week of 4, with average values ranging from 0.79 ± 0.03 to 0.51 ± 0.02 mgAA/gDW. The LSD test comparing the effects of the packaging materials indicated no significant differences between packaging materials Al/PE, P/PE, and PET ($p < 0.05$).

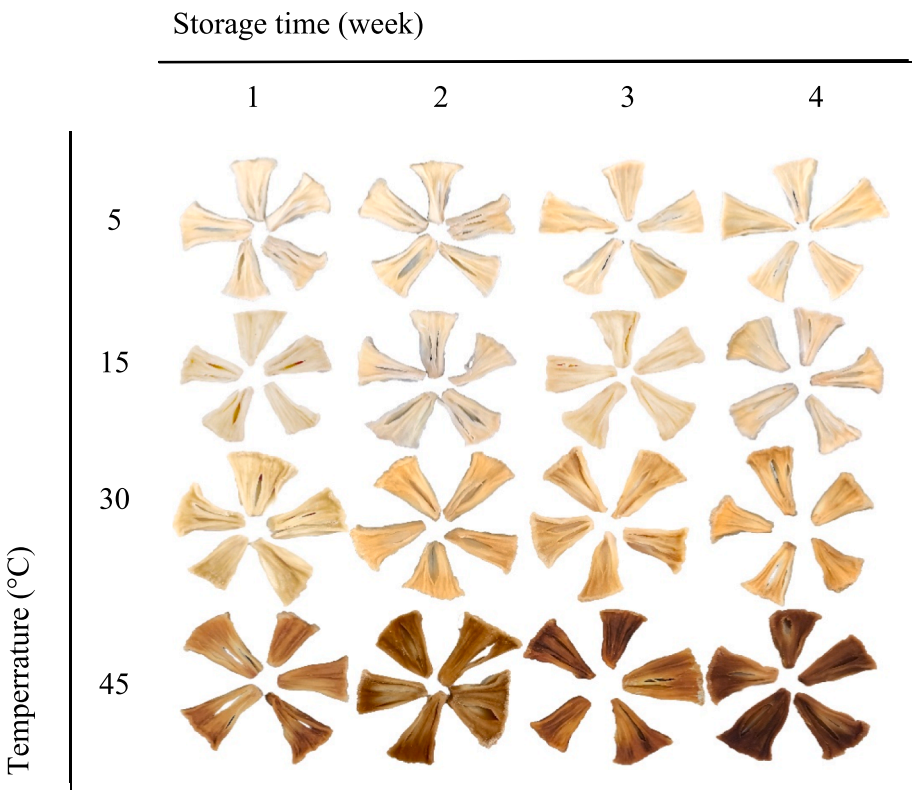

Fig. 4. Color change of soursop dried affected by temperature over time.

Among them, packaging material PET showed a higher DPPH value than the other packaging materials, with average values ranging from 0.91 ± 0.01 to 0.57 ± 0.04 mgAA/gDW. Similarly, the initial ABTS value before packaging was 0.94 ± 0.01 mgAA/gDW. After storage in packaging material P, the ABTS value decreased from week 1 to week of 4, with average values ranging from 0.78 ± 0.03 to 0.72 ± 0.01 mgAA/gDW. For packaging materials Al/PE and P/PE, the ABTS values were from (0.86 ± 0.02 to 0.79 ± 0.02 mgAA/gDW) and from (0.95 ± 0.01 to 0.78 ± 0.02 mgAA/gDW), respectively. Packaging material PET showed higher ABTS values compared to other packaging materials, with average values ranging from 0.97 ± 0.01 to 0.83 ± 0.01 mgAA/gDW when the ABTS value decreased from week 1 to week 4. The loss of bioactive elements such as polyphenols, flavonoids, and ascorbic acid from dried soursop jam may result in antioxidant activity. It has been shown that polyphenols may scavenge free radicals by various methods, including metal chelation, electron transfer, and donation of hydrogen ions. The capacity of high molecular weight phenolics (tannins) to neutralize free radicals like ABTS•+ and DPPH•+ is noteworthy. (González et al., 2017).

Total microbiology of soursop dried jam affected by the type of packaging over time

The quantification results of total aerobic microorganisms in the jam samples stored in different packaging materials showed an increasing trend over time (Table 2). All packaging materials observed the presence of microorganisms after one week of storage. However, the sample in packaging material P exhibited a significant increase in microbial count, reaching 6.8 times higher after two weeks (from 2.2×10^3 to 1.5×10^4 CFU/g), and continued to increase significantly in subsequent weeks. This is consistent with the high gas permeability of paper packaging compared to other types of packaging, which increases humidity and oxygen levels surrounding the product, forming favorable conditions for rapid microbial growth. Based on the results in Table 4, the samples in packaging materials Al/PE and PET still did not show the presence of mold after four weeks of storage, while packaging materials P and P/PE started to show mold presence in the third week, with the counts of (1.4×10^2 and 10^2 CFU/g), respectively. After four weeks, the sample in packaging material P exhibited a 1.7-fold increase in mold count from (1.4×10^2 to 2.5×10^2 CFU/g). The results indicated that the samples stored in PET packaging showed the presence of aerobic microorganisms and mold within the permissible limits (Total aerobic microorganisms < 10^4; Total yeast and mold spores $\langle 10^2$) according to regulation concerning the upper limits of biological and chemical contamination in food, Regulation No. 46/2007/QD-BYT (Ministry of Health,2007). The study results suggested that PET packaging material is a suitable material for packaging dried soursop jam. It can preserve and protect product quality, and effectively resist the adverse impact and collisions. Additionally, it has an attractive, convenient, and user-friendly design. Therefore, plastic jar packaging is suitable for storing dried jam under the following temperature conditions.

The effects of storage temperature on physicochemical properties, chemical composition, and microbial spoilage over time of dried soursop

The effects of storage temperature on color and moisture content of dried soursop

The L* value was significantly impacted by temperature and time ($p < 0.05$) (Fig. 4 and Table 3). In general, the L* value tended to decrease over the storage period. It fell by 10.9%, 13.9%, 19.78%, and 42.6% after four weeks of storage at the temperatures of 5, 15, 30, and 45 °C, respectively. This result is consistent with Patras et al., (2011), which also reported that lightness (L) value decreased at 4 and 15 °C during 28 days of storage ($p < 0.05$). A reduction in L* value during storage indicates the presence of non-enzymatic browning processes since it reflects the darkening of the surface color. Additionally, ΔE and BI also increased over the 4-week storage period ($p < 0.05$). The ΔE value typically increases with storage temperature (Coşkun, Türkyilmaz, et al., 2013). Similarly, in the study by Patras et al., (2011) where the influence of storage time and temperature on the color parameters of strawberry was investigated, showing a linear increase in after 28 days of storage ($p < 0.05$). Additionally, Liu et al., (2010) reported that ascorbic acid oxidation is crucial for non-enzymatic food browning. Dehydroascorbic acid is produced as the first step in the oxidation process, and it can then interact with amino acids to generate colors. This is consistent with the increase in BI and ΔE after 5 months of tomato powder storage, regardless of the storage temperature ($p < 0.05$). As the color changes of the fruits are influenced by both temperature and storage time, higher temperatures of 30 and 45 °C during extended storage adversely affect the product's color. Therefore, the temperatures of 5 and 15 °C provide good and stable color results during storage.

Moisture is a critical factor that determines the shelf-life of food products. During two weeks of storage process, all samples at different temperatures showed increasing moisture content. However, after four weeks of storage, the samples at 5 and 15 °C exhibited relatively stable moisture content, ranging from (18.563 ± 0.418 to 23.162 ± 0.935%) and from (17.797 ± 0.14 to 22.977 ± 0.093%), respectively, with no significant difference ($p > 0.05$). In contrast, at temperatures of 30 and 45 °C, the moisture content continuously increased throughout the storage period, ranging from (18.642 ± 0.158 to 25.001 ± 0.218%) and (18.772 ± 0.452 to 25.295 ± 0.053%), respectively. This can be

Table 3
Color and moisture content of soursop dried jam during storage with four temperatures.

Temperature(°C)	Time (week)	L*	ΔE	BI	Moisture (%)
	0	77.96 ± 1.45	0	18.45 ± 0.5	15.603 ± 0.328
5	1	72.12 ± 3.53^{Dc}	6.48 ± 2.8^{Aa}	27.52 ± 1.58^{Aa}	18.563 ± 0.418^{Aa}
	2	70.49 ± 2.94^{Db}	7.93 ± 1.19^{Ab}	28.08 ± 4.79^{Ab}	22.278 ± 0.249^{Ab}
	3	70.77 ± 3.59^{Da}	8.28 ± 1.99^{Ac}	31.65 ± 1.46^{Ab}	22.533 ± 0.074^{Ac}
	4	69.43 ± 2.96^{Da}	9.47 ± 2.02^{Ac}	31.66 ± 1.06^{Ab}	23.162 ± 0.935^{Ad}
15	1	69.25 ± 3.46^{Cc}	9.48 ± 0.95^{Ba}	28.82 ± 5.45^{Aa}	17.797 ± 0.14^{Aa}
	2	68.73 ± 1.9^{Cb}	9.47 ± 1.19^{Bb}	29.89 ± 2.46^{Ab}	22.624 ± 0.201^{Ab}
	3	69.17 ± 2.75^{Ca}	9.66 ± 1.37^{Bc}	31.8 ± 2.48^{Ab}	22.78 ± 0.562^{Ac}
	4	67.05 ± 4.55^{Ca}	11.52 ± 2.15^{Bc}	32.34 ± 0.5^{Ab}	22.977 ± 0.093^{Ad}
30	1	65.75 ± 3.23^{Bc}	12.5 ± 0.92^{Ca}	31.45 ± 0.41^{Ba}	18.642 ± 0.158^{Ba}
	2	65.06 ± 2.32^{Bb}	15.2 ± 2.14^{Cb}	43.75 ± 7.36^{Bb}	22.354 ± 0.001^{Bb}
	3	62.49 ± 2.92^{Ba}	17.27 ± 1.11^{Cc}	44.89 ± 5.3^{Bb}	22.978 ± 0.682^{Bc}
	4	62.54 ± 4.01^{Ba}	17.42 ± 3.88^{Cc}	44.8 ± 4.48^{Bb}	25.001 ± 0.218^{Bd}
45	1	62.07 ± 3.61^{Ac}	17.06 ± 4.09^{Da}	41.04 ± 8.91^{Ca}	18.772 ± 0.452^{Ca}
	2	51.75 ± 4.31^{Ab}	27.25 ± 2.31^{Db}	47.56 ± 4.62^{Cb}	22.801 ± 0.634^{Cb}
	3	44.83 ± 1.8^{Aa}	33.79 ± 0.77^{Dc}	51.09 ± 3.89^{Cb}	23.808 ± 0.6^{Cc}
	4	44.08 ± 3.91^{Aa}	34.85 ± 0.51^{Dc}	52.37 ± 9.97^{Cb}	25.295 ± 0.053^{Cd}

[A-D]: Values in the column with various capital letters, corresponding to various packing types, are significant at the $P < 0.05$ level. [a-e]: The values in the lowercase lettered column are different, and the difference in storage time is significant at the $P < 0.05$ level.

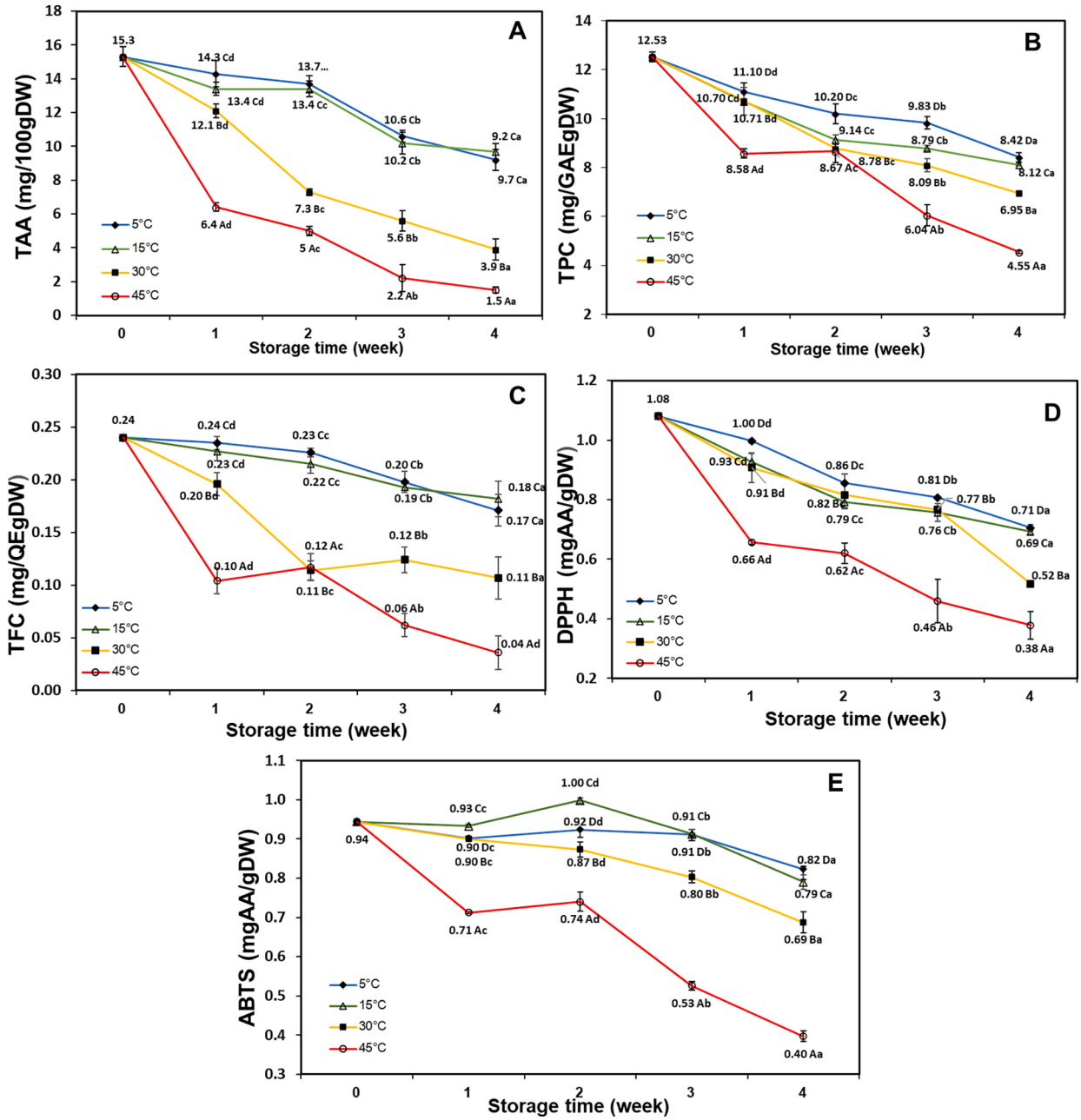

Fig. 5. Variation of TAA (A), (TPC) (B), TFC (C), DPPH (D), and ABTS (E) content of soursop dried affected by temperature during four weeks of storage.

explained by the fact that the product contains sugar in a bound form that is absorbed during processing, and when stored at high temperatures for a long time, the bond structure of the sugar can be weakened, leading to a decline in the product's structure. In this case, the bound water in the sample quickly changes from the bound form to the free state.

The effect of storage temperature on TAA, TPC, TFC and antioxidant activity of dried soursop

TAA showed a significant decreasing trend over the storage time ($p < 0.05$). The samples stored at 30 and 45 °C experienced the most significant reduction in TAA from (12.1 ± 0.4 to 3.9 ± 0.64 mg/100gDW) and from (6.4 ± 0.25 to 1.5 ± 0.17 mg/100gDW) after four weeks of storage, respectively (Fig. 5A). Meanwhile, the TAA of samples stored at 5 and 15 °C also decreased non-significantly, from (14.3 ± 0.78 to 9.2 ± 0.64 mg/100gDW) and (13.4 ± 0.4 to 9.7 ± 0.46 mg/100gDW), respectively. Similar results have been reported in the study by Yao et al., (2020), in which the TAA of dried mango slices stored at 37 and 50 °C significantly decreased ($p < 0.05$) regardless of the packaging system during the storage process. High temperatures and longer storage times accelerated the loss of L-ascorbic acid in mango powder (Hymavathi & Khader, 2005). Through non-enzymatic processes, the oxidation of L-ascorbic acid plays a significant role in food browning and loss of vitamin C. In addition, L-ascorbic acid in berries is more susceptible to the kinetics of its degradation during storage, with storage temperature having a substantial impact on this degradation. In a study by Ri & Rao, (2018), after 28 days of storage, the vitamin C content of strawberry jam reduced by 50% at 4 °C and 70% at 15 °C. Low storage temperatures proportionally affected TAA maintenance, as reported by Begum Ahmed & Rahman (2009).

The most prevalent antioxidants in the human diet are phenolic compounds, which are frequently present in fruits and vegetables. The antioxidant properties of these substances are of interest. The changes in TPC and TFC (Fig. 5B and C) during the storage of dried soursop indicate

Table 4
Microbiological test results.

Temperature (°C)	Time (week)	Total aerobic microorganisms (CFU/g)	Total yeast mold (CFU/g)
5	1	2.4×10^3	U
	2	2.5×10^3	U
	3	3.4×10^3	U
	4	3.1×10^3	U
15	1	2.1×10^3	U
	2	2.6×10^3	U
	3	3.1×10^3	U
	4	4.3×10^3	U
30	1	2.2×10^3	U
	2	2.5×10^3	U
	3	4.9×10^3	10^2
	4	5.8×10^3	10^2
45	1	2.6×10^3	U
	2	2.7×10^3	U
	3	5.4×10^3	10^2
	4	5.1×10^3	2.7×10^2

U_Undetectable.

that time and temperature have an impact on these levels ($p < 0.05$). The initial TPC of the sample before packaging was 12.53 ± 0.2 mgGAE/gDW. A significant loss in TPC was observed after four weeks of storage at 30 and 45 °C, ranging from (10.71 ± 0.1 to 6.95 ± 0.09 mgGAE/gDW) and (8.58 ± 0.2 to 4.55 ± 0.05 mgGAE/gDW), respectively. This significant loss is consistent with the findings of Louaileche & Djaoudene, (2016), in which a significant loss of TPC (17–20%) was observed after 30 days of storage at 25 and 35 °C for orange jam, due to oxidation and polymerization. At 5 and 15 °C, the TPC decreased from (11.1 ± 0.37 to 8.42 ± 0.2 mgGAE/gDW) and from (10.7 ± 0.57 to 8.12 ± 0.06 mgGAE/gDW), respectively, corresponding to a loss rate of 32.8% and 35.2% in the fourth week compared to the control sample. Similar findings were obtained by Patras et al., (2011), which noted TPC loss rates of 24.2%, 26.3%, and 31.6% on days 7, 14, 21 in comparison to the control sample maintained at 4 °C. On the other hand, TPC of strawberry jam during storage at 15 °C was reduced by 28.6%, 22.5%, 34.8%, and 17.6% ($p < 0.05$). The enzymes lipoxygenase (LOX) and peroxidase (POD) can affect the loss of TPC in soursop. These enzymes oxidize phenols and function as the catalysts in the oxidation process after oxidizing metal ions (Vu et al., 2022). Due to the heat durability of the enzymes in the soursop and the high concentration of POD relative to other enzymes, the soaking technique used in the present study did not completely inactivate the enzymes. However, Eskin et al., (1977) previously stated that enzymes could not be completely inactivated. Similarly, the TFC content also significantly decreased after four weeks of storage at all four temperature levels ($p < 0.05$) (Fig. 5C). In the fourth week, TFC decreased by 29.1%, 25%, 54.2%, and 83.3% compared to the control sample for the samples stored at 5 °C, 15 °C, 30 °C, and 45 °C, respectively. Overall, TPC and TFC decreased as the temperature increased. On the other hand, as flavonoids are relatively sensitive to heat, their cellular degradation leads to the release and hydrolysis of oxidative enzymes which potentially destroy antioxidant compounds (Zzaman et al., 2021). In the study by Patras et al., (2011) it was suggested that during processing, the disruption of cellular structure expose the fruit to non-enzymatic oxidation, which may be one of the primary causes of the loss of phenolic chemicals during storage. Therefore, this partially explains the factors contributing to the loss of TPC and TFC in dried soursop.

Various antioxidant compounds, with unique mechanisms of action, influence a food's antioxidant activity. Thus, the antioxidant capacity of food must be assessed using various techniques and processes (Moo-Huchin et al., 2014). Therefore, the antioxidant activity was determined using DPPH and ABTS scavenging assays, and the results are shown in Fig. 5D and E. Overall, the antioxidant activity of dried soursop jam decreased over time at all temperature levels ($p < 0.05$). The results showed that the initial DPPH scavenging activity of the dried soursop decreased by 34.26%, 36.1%, 51.9%, and 64.8% after 4 weeks of storage at 5, 15, 30, and 45 °C, respectively. Similarly, ABTS scavenging activity was 14.89%, 15.95%, 26.6%, and 57.44% after 4 weeks of storage at 5, 15, 30, and 45 °C, respectively. According to Louaileche & Djaoudene, (2016), after 30 days of storage at 25 and 35 °C, the antioxidant activity of orange jam was reduced by 48.5% and 56%, respectively. This can be explained by the fact that certain fatty acids present on the cell structures are oxidized due to persistent heat stress. In addition, at the temperatures over 40 °C, the H_2O_2 concentrations and the lipid peroxidation product malondialdehyde in plant tissues considerably increased, thus reducing the content of bioactive molecules such as flavonoids and phenolics as well as their antioxidant activity as a response to different temperature and storage duration.

Total microorganisms of dried soursop affected by storage temperature over time

U_Undetectable.

Table 4 shows that all types of packaging recorded the presence of microorganisms after 1 week of storage and remained stable until the second week. However, after 3 weeks, the samples at 30 and 45 °C showed a nearly two-fold increase in the number of microorganisms compared to the second week, with counts ranging from (2.5×10^3 to 4.9×10^3 CFU/g) and (2.7×10^3 to 5.4×10^3 CFU/g), respectively, and continued to increase in the subsequent weeks. After 4 weeks of storage, a significant increase in the microbial load was observed at 5 °C, while the microbial count remained stable at the remaining temperatures. It can be seen that the samples at 5 and 15 °C did not show the presence of mold after four weeks of storage, while at 30 and 45 °C, mold began to appear in the third week at a count of 10^2 CFU/g. After 4 weeks, the sample at 45 °C had a 2.7 fold increase in mold count from 10^2 to 2.7×10^2 CFU/g. The results indicate that the samples stored at 5 and 15 °C showed the presence of aerobic microorganisms and mold within allowable limits (Total aerobic microorganisms $< 10^4$; total fungal and mold spores (10^2) based on the guidelines outlined in Decision 46/2007/QD-BYT (Ministry of Health,2007) about the upper limits of biological and chemical contamination in food.

Conclusions

Results from the present study showed that paper packaging had the most significant effects on the deterioration of color, physicochemical qualities, chemical composition, and biological activity of all packaging types. Meanwhile, approximately 76.26 % of TPC, 37.03 % of TFC, 62.63 % of DPPH, and 88.29 % of ABTS were retained when preserved in plastic jar packaging. Furthermore, the packaging type and storage time contributed to decreased initial color of the dried soursop. Plastic jar packaging was considered as suitable for preserving the dried soursop. High temperatures (30 and 45 °C) affected the quality of the dried soursop more significantly than lower temperatures (5 and 15 °C). The recommended storage temperature is 15 °C. The obtained results after four weeks showed an average moisture content of 22.977 ± 0.093 %, remaining 63.4 % of TAA, 64.8 % of TPC, 75 % of TFC, and DPPH/ABTS antioxidant activity of the dried soursop at 63.88 % and 84.04 %, respectively compared to the initial values. The product meets the requirements of decision 46/2007/QD-BYT (Ministry of Health, 2007) regulating limits on biological and chemical contamination in food. The microbial quality met permissible limits for Vietnam.

CRediT authorship contribution statement

Thi Nhu Quynh Le: Investigation, Methodology, Software, Validation, Writing – original draft. **Yen Vy Do:** Investigation, Methodology, Software. **Ngoc Quy Nguyen:** Formal analysis, Methodology, Validation. **Thi Yen Nhi Tran:** Formal analysis, Methodology, Validation. **Bao Long Huynh:** Methodology, Validation. **Long Giang Bach:** Project administration, Resources, Software, Supervision. **Bui Thi Thu Thao:**

Methodology, Validation, Software. **Tan Phat Dao:** Project administration, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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