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Effect of different sugars on non-enzymatic browning and flavor in Choerospondias axillaris composite fruit puree using principal component analysis

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Abstract

A Non-enzymatic browning reaction of *Choerospondias axillaris* composite fruit puree has occurred during storage, which diminishes its edibility. In this study, the effects of sucrose, maltose, and glucose on the quality and flavor of fruit puree were investigated by analyzing the changes in non-enzymatic browning-related indicators. The results showed that after 7 days of storage, the highest levels of total phenols (1.578 mg/mL), Vitamin C (3.084 mg/100g), and reducing sugars (1.692 mg/mL) were found in glucose + maltose, sucrose, and maltose, respectively; Sucrose resulted in the lowest browning index (0.268) and pH value (3.29); The lowest HMF content (0.597 mg/L) was observed in the glucose. Changes in the content of various indicators suggest that the degradation of Vitamin C may be the primary mechanism of non-enzymatic browning in the early stages of fruit puree storage. Aroma composition and principal component analysis indicate that the contribution of sweeteners to flavor substances, from highest to lowest, is glucose, maltose, and sucrose. The top four overall score rankings are sucrose, glucose + sucrose, maltose, and glucose + maltose + sucrose.

Introduction

Choerospondias Axillaris (CA) is a pioneer fruit tree species that belongs to the Anacardiaceae family (Noora, 2020). CA, primarily found in the warm temperate regions of China and in countries such as Japan, India, and Nepal, is rich in nutritional compounds, including pectin, organic acids, polyphenols, and flavonoids (Li et al., 2016). Flavonoids, in particular, have various beneficial effects such as anti-inflammatory, antioxidant, anti-tumor, blood sugar regulation, and immune enhancement (Mann et al., 2022). However, most CA products have high sugar content, which can adversely affect human health. In order to reduce the sugar content and enrich the diversity of CA products, the research team developed a composite puree of CA, snow pear, and apple (Ye et al., 2023), which not only harmonizes the sweet and sour taste of the fruit puree but also increases the flavor of the fruit puree. This product can be used as supplemental food for infants and elderly diabetics, significantly expanding the CA series products market.

The browning of fruits and vegetables can be categorized as enzymatic and non-enzymatic browning (NEB). Due to heat treatment during processing, enzymes are inactivated before storage, making non-enzymatic reactions the primary cause of browning during storage. NEB reactions have been classified into four main categories: Maillard reaction (MR), caramelization reaction, Vitamin C (VC) degradation, and polyphenol oxidation-condensation (Liu et al., 2023a). Caramelization reaction typically occurs at high temperatures (140–170°C), so the NEB observed in fruit puree during storage may result from the combined effects of the MR, VC degradation, and polyphenol oxidation-condensation. NEB not only affects the color and flavor of fruits and vegetables but also results in nutrient losses, reducing their nutritional value (Wang et al., 2013). The primary mechanism of NEB varies in different fruit systems. Studies by Babsky (1986) and David (1986) have demonstrated that browning in apple and pear juices is primarily due to the MR, while in acidic fruit juices such as lemon and orange, it is mainly caused by VC degradation (Kathuria and Thakur, 2023).

CA fresh fruit sour and the astringent flavor is heavy; the reconciliation of taste has become a problem that must be solved in processing CA products. Sugars like sucrose, maltose, and glucose are often used in food processing to neutralize the acidity of products. Most research on CA has focused on product development and browning control, with limited studies on the influence of sugar types on the quality of CA composite purees during storage. This study aims to elucidate the contributions of different sugar types to the early-stage NEB and flavor substances in composite fruit puree, attempting to explain the primary mechanisms of NEB. Given the limited impact of single indicators, which cannot objectively reflect the overall quality of fruit puree, a comprehensive evaluation model for fruit puree quality is established through principal component analysis (PCA) based on physicochemical indicators related to NEB and significant aroma components. The comprehensive scores obtained from this model can determine the quality level of the composite fruit puree.

In this study, total phenols, VC, 5-hydroxymethylfurfural (HMF), browning index, pH, and reducing sugars are examined as parameters to evaluate the changes in physicochemical indicators and aroma components of the fruit puree during early-stage storage. Additionally, PCA is applied to these indicators to construct an evaluation model. This study aims to investigate the impact of these three sugars on the quality of the composite fruit puree, providing a valuable reference for the processing of CA products.

Materials and Methods

Materials and Reagents

CA pulp was supplied by Hongye (Sichuan, China) and stored at -18°C until use. Apples, snow pears, and sugar were purchased from local supermarkets. 5-hydroxymethylfurfural (HMF, > 99%) was purchased from Aladdin (Shanghai, China). 3,5-Dinitrosalicylic acid (DNS) was purchased from Phygene (Fujian, China). All other chemicals used in this study were purchased from Kelong (Sichuan, China).

Preparation of fruit puree

High-quality snow pears and apples were peeled and cut into chunks. They were blanched separately in boiling water for 7 min for snow pears and 8 min for apples to deactivate enzymes. The blanched fruit chunks were then cooled to room temperature in ice water, filtered, and processed into fruit puree using a wall breaker. CA pulp was first processed with water in a 1:2 ratio to obtain CA puree. Then, CA, snow pear, apple, sweeteners, and water were mixed in a ratio of 8:8:6:3:16. The resulting composite fruit puree was packaged in 200 g of each bag, ensuring minimal air remaining in the bags and sealed. The sealed samples were subjected to sterilization at 77°C for 10 min. Finally, the fruit puree was cooled to room temperature in ice water and stored in a refrigerator at 4°C for further use.

Experimental design

During the fruit puree preparation, sweeteners, including glucose, sucrose, and maltose, were added individually or in combination. Based on the types of sugar added, the fruit puree was divided into seven groups: glucose (G), sucrose (S), maltose (M), glucose + sucrose in a 1:1 ratio (GS), glucose + maltose in a

1:1 ratio (GM), maltose + sucrose in a 1:1 ratio (MS), and glucose + maltose + sucrose in a 1:1:1 ratio (GMS). These seven groups of fruit puree were stored in a refrigerator at 4°C for 7 days. Various parameters were measured before and after storage to assess the changes.

Physicochemical analysis of puree

Determination of total phenolic content(TPC)

Modified from the Folin-Ciocalteu method (Kähkönen et al., 1999), 5 g of fruit puree was mixed with 5 mL of anhydrous ethanol. After standing at 4°C for 30 min, the mixture was centrifuged at 10,000 rpm for 10 min at 4°C. Then, 0.1 mL of the supernatant was taken and diluted with 1 mL of distilled water. Next, 1 mL of Folin's phenol reagent and 5 mL of 5% sodium carbonate solution were added to the mixture. The reaction was allowed to proceed in the dark for 1 h. The absorbance at 765 nm was measured using a spectrophotometer (UV-19001; shimadzu Instrument Co., Ltd., Jiangsu, China). The content of TPC in the sample was calculated according to the gallic acid calibration curve of 0.1 ~ 5 mg/mL (R^2 = 0.9996).

Determination of 5-hydroxymethylfurfural (HMF) content

HPLC (LC-2030C 3D Plus; shimadzu nterprise Management Co., Ltd., Shanghai, China) was used to measure HMF content in composite fruit puree samples. Sample preparation: 10 g of the sample was added to 20 mL of ethyl acetate, thoroughly mixed, and extracted for 30 min. Afterward, the mixture was centrifuged at 5000 rpm for 10 min at 4°C. The supernatant was transferred to a beaker containing 5 g of anhydrous sodium sulfate, dehydrated for 30 min, and then filtered. The remaining residue was dissolved in 1 mL of methanol and 1 mL of ultrapure water, followed by filtration through a 0.45 nm nylon filter membrane. The mobile phase (methanol/water, 5/95, v/v) and the flow rate of the detector were defined as 1 mL/min and 284 nm, respectively. This study determined HMF content using UV spectroscopy and the retention time of external standard HMF (Pham et al., 2020). Finally, the HMF contents of the samples were calculated according to the calibration curve obtained with those external standards ranging between 0.1 ~ 100 mg/L (R^2 = 0.9999).

Determination of VC content

The 2,6-dichloroindophenol method measured VC content (Varming et al., 2013). 10 g of the sample were mixed with 10 mL of a 20 g/L oxalic acid solution and vortexed for 1 minute. After centrifugation at 10,000 rpm for 5 minutes at 4°C, the supernatant was titrated with a 2,6-dichloroindophenol sodium salt solution until it turned pink.

Determination of browning index(BI)

Following Pham's method (2019), 5 g of fruit puree was placed in a centrifuge tube and mixed with 5 mL of 95% ethanol. After centrifuging at 10,000 rpm for 10 min at 4°C, the absorbance of the supernatant was measured at 420 nm wavelength with 50% ethanol as a reference solution.

Determination of pH

The fruit puree to be tested was poured into a beaker and stirred well. The pH of the samples was measured at room temperature using an automatic potentiometric titrator (ZDJ-4A; Kehuan Analytical Instrument Co., Ltd., Nanjing, China).

Determination of reducing sugar content

Reducing sugars were measured using the 3,5-dinitrosalicylic acid (DNS) colorimetric method. 0.5 g of the sample was placed in a beaker, and 40 mL of distilled water was added. The mixture was heated in a water bath at 50°C for 20 min with continuous stirring. Then, 0.5 mL of the supernatant and 1.5 mL of DNS solution were added to a colorimetric dish. The reaction was conducted in boiling water for 5 min. After cooling, the volume was adjusted to 25 mL, and the absorbance was measured at 494 nm. The sample's reducing sugar content was calculated according to the glucose calibration curve of 0.1 ~ 5 mg/mL (R^2 = 0.9996).

Determination of volatile flavor substances in fruit purees

Solid-phase microextraction heads were used to enrich for aroma (65 μm PDMS/DVB; Supelco Ltd., PA, USA): 5 g of the sample was placed in a 15 mL gas-phase vial, 5 mL of saturated NaCl solution was added, and the sample was extracted by SPME headspace at 50°C for 30 min. Qualitative and quantitative analysis of fruit puree by GC-MS (7890A-5975B; Agilent Technologies Inc., CA, USA). GC conditions: inlet temperature 230°C; initial column temperature 45°C (5 min), then ramped at 5°C/min to 190°C (25 min). MS conditions: Electron impact ionization (EI) source with electron energy of 70 eV, ion source temperature of 230°C; mass scan range m/z 25 ~ 350.

Qualitative analysis: The mass spectra of the compounds were identified in the universal library (NIST11, NIST11s), and the compounds with matches greater than or equal to 80 were recorded for preliminary identification. Quantitative analysis: The peak area normalization method was used for quantification to obtain the relative content of each volatile substance.

Development of index evaluation model

PCA was used to analyze the data, reducing complexity and identifying the most essential features. Assuming there are n samples in a real problem, each sample has p indicators, which are considered p random variables and recorded as X_1, X_2 ... X_p. The *p* indicators were standardized through PCA, dimensionality reduction was performed, and linear regression was conducted based on Eq. (1) to form k principal components (PC_S) F_1, F_2... F_k ($k \leq p$).

$F_1 = u_{11}ZX_1 + u_{21}ZX_2 + ... + u_{p1}ZX_p$

$F_2 = u_{12}ZX_1 + u_{22}ZX_2 + ... + u_{p2}ZX_p$

...

$F_k = u_{1k}ZX_1 + u_{2k}ZX_2 + ... + u_{pk}ZX_p$ (1)

Where u represents the linear combination coefficients, $u = \frac{a}{\sqrt{\lambda}}$, a denotes factor loading, λ stands for eigenvalues, and ZX represents the standardized values of indicator variables. By using the variance contribution βi of each principal component as weight factors, a comprehensive evaluation function (2) was constructed.

$Y = \beta_1F_1 + \beta_2F_2 + ... + \beta_mF_m$ (2)

Scores for CA composite puree samples with different types of sugars were calculated, ranked, and used to evaluate their overall quality.

Data processing

Experimental results were analyzed using Excel 2019, and the indicators were subjected to analysis of variance (ANOVA) using SPSS 22. Multiple comparison analysis was performed to determine significance levels, where $p < 0.05$ indicated significant differences. Origin 2021 software was used for graphing and PCA analysis.

Results and discussion

NEB reactions occurring during storage

This study investigated the factors influencing NEB in fruit puree during storage. Polyphenols, VC, and reducing sugars are vital substrates for phenolic compound oxidation-condensation, VC degradation, and MR, respectively. The changes in their content were closely related to NEB. Regular consumption of vegetables and fruits has been associated with a significant reduction in cancer risk (Mentella et al., 2019), primarily due to the presence of antioxidants in fruits and vegetables, such as VC, phenolic compounds, and lycopene. CA is rich in phenolic compounds (Li et al., 2016) and can be further developed into functional foods. However, most phenolic substances are unstable (Ma and Waterhouse, 2018) and prone to non-enzymatic oxidative polymerization to form brown substances, resulting in nutrient loss and color browning.

As shown in Fig. 1A, the sugar-type effect on TPC was insignificant ($p > 0.05$). With extended storage time, the TPC decreased in all samples except for a slight increase in the GM sample. On the 7th day of storage, the TPC of the GM sample was the highest (1.578 mg/mL). The TPC in G sample was the lowest (1.180 mg/mL), which decreased by 26.57% compared to day 0. The decline in TPC is attributed to the self-oxidative condensation of phenolic compounds in the compound fruit puree (Dong et al., 2016), which is consistent with the results of browning caused by the decrease in TPC in apple juices (Xu et al., 2023). Previous research suggests that phenolic acids are more stable at low pH and have slower auto-oxidation rates of polyphenols (Lund, 2021). As pH increases, the oxidation rate of phenolic compounds accelerates (Danilewicz, 2012). This study focused on CA compound fruit puree, an acidic system, further confirming that the phenolic compounds oxidation rate is slower in a low pH environment, contributing minimally to NEB in the fruit puree.

VC is highly unstable during processing and storage. Studies have shown that the degradation products of VC are related to browning, as VC can decompose to form furfural and HMF, and these degradation products of VC can react with amino compounds to form brown pigments (Damasceno et al., 2008). Moreover, a higher initial VC concentration promotes its degradation in the system (Laroque et al., 2008). As depicted in Fig. 1B, the effect of different sugar types on VC content was significant ($p < 0.05$). After 7 days of storage, there was a significant decrease in VC content in all samples, with the S sample having the highest content at 3.084 mg/100g, which degraded by approximately 66.64%. The MS sample experienced the most significant VC loss, with a degradation of approximately 82.19%. It can be observed that the effect of adding different sugars on the VC content in the composite puree was much less than that of storage time, indicating that the effect of storage time on the NEB of the puree should not be neglected.

HMF originates from the 1,2-enolization, hexose cyclization reactions, and the degradation of Amadori products in the MR (Chen et al., 2019a). It is considered one of the quality indicators for various processed fruits (Lee et al., 2014). As shown in Fig. 1C, the HMF content in each sample was similar before storage but increased in all samples during storage. The GM sample exhibited the highest HMF content at 0.916 mg/L, representing an increase of about 63.57%. This phenomenon was attributed to the fact that the GM sample contained only reducing sugars, and the initial VC content was the highest in this system. HMF is both an intermediate product of the MR (Godoy et al., 2022) and a degradation product of VC. Consequently, the HMF content in the GM sample was significantly higher than in the other samples ($p < 0.05$). Under acidic conditions, sucrose is easily hydrolyzed, and its hydrolysis products, fructose and glucose, act as the primary reactants in the MR. Nayaka et al. (2022) demonstrated that sucrose contributes to the formation of HMF in the NEB of pomegranate peel. However, its contribution to the MR is less significant than that of monosaccharides.

During the storage process, the BI of fruit puree increased in all systems. However, the degree of increase was not the same (Fig. 1D). The M sample exhibited the highest BI before and after storage, at 0.425 and 0.652, respectively, significantly higher than other fruit puree systems ($p < 0.05$). The GM sample showed the highest increase in BI after 7 days of storage (105.11%), while the S sample had the slightest change in BI, with an increase of only 10.29%. The increase in BI in compound fruit puree reflects the impact of NEB. Based on Fig. 1B and 1C, the GM sample was affected by VC degradation and the MR, leading to an increase in BI. The consistency between BI increase, HMF content increase, TPC decrease, and VC content decrease indicates that phenolic compounds and VC contribute to NEB during storage.

pH is a crucial factor indirectly affecting NEB, as demonstrated by Dong et al. (2016), who showed that pH significantly affects polyphenol-mediated NEB. Studies by Pham et al. (2020) suggested that VC is more prone to degradation in lower pH environments. As shown in Fig. 1E, the pH values of different fruit puree systems ranged from 3.2 to 3.4, indicating acidic products. The addition of sweeteners significantly affected the pH of the compound fruit puree ($p <$

0.05), but the effect of storage time on the pH of the compound fruit puree was minimal. The S sample exhibited the lowest pH values before and after storage, at 3.28 and 3.29, respectively. Combining the analysis of BI, the decrease in pH led to a reduction in the extent of NEB, consistent with the findings of Quayson et al. (2021). However, Dorris et al. (2018) suggested that low pH values can increase the initial BI of CA.

The carbonyl-amino reaction between free-reducing sugars and free amino acids is one of the factors influencing NEB in processed fruits and vegetables (Paravisini and Peterson, 2018). As illustrated in Fig. 1F, the addition of different sugar types significantly affected the content of reducing sugars in the composite fruit puree ($p < 0.05$). After 7 days of storage, the S and M samples showed increased reduced sugar content, reaching a maximum of 1.692 mg/mL. In contrast, the other sample experienced a decrease in reduced sugar content, with the G sample losing nearly 67.34%. Sucrose and maltose, as disaccharides, hydrolyzed into monosaccharides in the early storage stages, increasing reduced sugar content. However, as a monosaccharide, glucose could directly participate in browning reactions in the early storage stages, resulting in significant losses in reducing sugar content.

Additionally, fruit puree with added complex sugar experienced a lesser reduction in reducing sugar content, reflecting that the NEB in the early storage of these fruit purees is primarily dominated by VC degradation rather than the MR. This finding is similar to the results of Pham et al. (2021). However, Paravisini and Peterson (2019) suggested that MR is the primary mechanism of NEB in orange juice, which may be due to differences in fruit types and processing conditions.

Analysis of aroma components

The analysis of aroma components in 10 types of fruit puree (Table 1) revealed the presence of a total of 49 volatile flavor compounds, categorized into seven classes: alcohols, terpenes, esters, alkanes, aldehydes, ketones, and acids. In the composite fruit puree, pentanal was identified as the characteristic aroma compound for the S sample, while furfuryl alcohol, γ-butyrolactone, and furfural were the distinctive aroma compounds for the M sample. The G sample exhibited specific aroma compounds such as 2-octanol, 2-morpholinoethanol, 2-ethylhexanol, cyclooctatetraene, d-limonene, benzocyclobutene, tridecane, tetradecane, and nonadecane. The GM sample featured hexyl isobutyrate as its unique aroma compound, while the GMS sample contained 1-pentanol, isopentanol, and hydroxyacetone as its distinctive aroma compounds. Notably, the S sample had the fewest types of aroma compounds, and both MS and GS samples did not exhibit specific aroma compounds. This result suggests that the contribution of sweeteners to flavor substances, from highest to lowest, is glucose, maltose, and sucrose.

Table 1
Aroma composition analysis

Code	Name of substance	Comparative content/%									
		CA	Snow pear	Apple	S	M	G	MS	GS	GM	
Alcohols											
A1	Ethyl alcohol	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0
A2	α-Trepineol	3.48	-	-	-	-	-	-	-	-	-
A3	1-Butanol	-	-	0.07	0.11	-	0.06	0.10	0.10	-	0
A4	1-Hexanol	-	-	0.36	0.60	0.52	0.33	0.53	0.55	-	0
A5	1-Octanol	-	-	1.09	-	-	-	-	-	-	-
A6	1-Pentanol	-	-	-	-	-	-	-	-	-	0
A7	1-Nonanol	-	-	1.68	-	-	-	-	-	-	-
A8	Eucalyptol	-	2.56	-	-	-	-	-	-	-	-
A9	2-Methyl-1-butanol	-	-	-	0.29	0.25	0.16	-	-	-	-
A10	2-Octanol	-	-	-	-	-	1.01	-	-	-	-
A11	2-Morpholinoethanol	-	-	-	-	-	1.03	-	-	-	-
A12	S- (-) -2-methyl-1-butanol	-	-	-	-	-	-	0.26	0.27	0.24	0
A13	Isoamyl alcohol	-	-	-	-	-	-	-	-	-	0
A14	2-Ethyl hexanol	-	-	-	-	-	1.02	-	-	-	-
A15	Furfuryl alcohol	-	-	-	-	0.37	-	-	-	-	-
Terpenes											
B16	1-Caryophyllene	8.07	-	-	-	-	-	7.34	7.58	6.92	4
B17	α-Caryophyllene	8.07	-	-	-	-	-	-	-	-	-
B18	α-Pinene	8.06	-	-	-	-	4.59	7.34	7.58	6.91	-
B19	Cyclo-octatetraene	-	-	-	-	-	0.37	-	-	-	-
B20	D-limonene	-	-	-	-	-	1.16	-	-	-	-
B21	Dipentene	-	1.52	-	-	-	-	-	-	-	-
B22	Benzocyclobutene	-	-	-	-	-	0.37	-	-	-	-
Ester											
C23	Ethyl butyrate	-	0.79	0.66	1.10	-	0.61	-	1.00	0.91	0
C24	Hexyl isobutyrate	-	-	-	-	-	-	-	-	4.35	-
C25	Butyric acid hexylester	-	-	-	-	-	-	4.61	4.76	-	-
C26	Butyl acetate	-	-	0.65	1.09	0.95	0.61	0.97	1.00	0.91	0
C27	Ethyl 2-methylbutyrate	-	1.32	1.44	1.81	1.58	1.00	1.60	1.66	1.51	0.89
C28	Propyl acetate	-	0.42	-	-	-	-	-	-	-	-
C29	Thyl propionate	-	0.42	-	-	-	-	-	-	-	-
C30	Ethyl Hexanoate	-	2.02	-	-	-	-	-	-	-	-
C31	Ethyl acetate	-	0.20	-	-	-	-	-	-	-	0.13
C32	Valeric acid ethylester	-	1.31	-	-	-	-	-	-	-	-
C33	Hexylacetate	-	-	-	5.57	3.25	1.54	2.47	4.25	2.32	1.37
C34	Amyl acetate	-	-	-	-	1.58	1.00	-	1.65	-	-
C35	Hexyl ether formate	-	-	-	-	1.58	-	-	1.65	1.50	-
C36	γ-Butyrolactone	-	-	-	-	0.20	-	-	-	-	-
Ethers											

Code	Name of substance	Comparative content/%									
		CA	Snow pear	Apple	S	M	G	MS	GS	GM	
D37	Dodecamethyl cyclohexasiloxane	24.17	18.00	14.86	24.84	21.70	13.75	21.99	22.71	20.72	16.2
D38	Decamethyl cyclopentasiloxane	21.72	16.17	13.35	37.21	39.01	12.36	19.77	20.41	31.03	25.5
D39	Octamethylcyclotetrasiloxane	16.52	36.91	44.01	16.98	19.78	28.21	15.04	15.53	14.16	33.2
D40	Hexamethylcyclotrisiloxane	9.86	17.14	20.21	10.14	8.86	14.97	17.95	9.27	8.46	16.5
D41	Tridecane	-	-	-	-	-	3.54	-	-	-	-
D42	Tetradecane	-	-	-	-	-	4.30	-	-	-	-
D43	Nonadecane	-	-	-	-	-	8.01	-	-	-	-
Aldehydes											
E44	Nonanal	-	-	1.59	-	-	-	-	-	-	-
E45	Furfural	-	-	-	-	0.32	-	-	-	-	-
E46	Pentanal	-	-	-	0.23	-	-	-	-	-	-
Ketone											
F47	2-Octanone	-	1.21	-	-	-	-	-	-	-	-
F48	Hydroxyacetone	-	-	-	-	-	-	-	-	-	0.05
Acids											
G49	Acetic acid	0.03	-	-	-	0.03	-	0.03	0.03	0.03	0.02

Aroma components with relatively high relative contents in all samples were alkanes, terpenes, esters, and alcohols, accounting for 82.54%, 8.00%, 7.33%, and 1.79% of the total content, respectively. Alkanes were found to be the significant flavor constituents in fruit puree, but they have a high flavor threshold and generally weak or no aroma and may have synergistic effects with other flavor substances. The composite fruit puree GMS contained a high proportion of alkane compounds (91.61%), with compounds such as dodecamethylcyclohexasiloxane, decamethylcyclopentasiloxane, octamethylcyclotetrasiloxane, and hexamethyltrisiloxane detected in all samples.

Terpenes were notably more abundant in CA puree (24.20%) compared to other fruit purees, with compounds such as 1-caryophyllene, α-caryophyllene, and α-pinene originating from CA, and dipentene from snow pear. In the composite fruit puree samples GS, MS, and GM, terpene content was relatively high and similar, constituting 15.16%, 14.68%, and 13.83%, respectively. In contrast, terpenes were not detected in the S and M samples. Compared with CA puree, compound fruit puree increased by three kinds of terpenes. Cyclooctatetraene (0.37%), dextral terpene diene (1.16%), and benzocyclobutene (0.37%) were increased in the G sample. Among these, α-Pinene has pine and resin-like odors, and dextral terpene diene has a light floral fragrance.

Ester compounds are primarily produced through the esterification reaction of alcohols (Selli, 2007) and contribute to fruits' sweetness and fruity flavor (Ban et al., 2010). Compared to single fruit purees, the compound fruit purees contained additional ester compounds, including hexyl isobutyrate, hexyl butyrate, hexyl acetate, amyl acetate, hexyl formate, and γ-butyrolactone. Among these, the GS sample had the highest ester compound content (15.97%) with the most variety. Studies have shown that acetate esters are one of the primary beneficial esters (Li et al., 2017). Hexyl acetate, a newly formed ester compound, was present in all composite fruit purees and had a relatively high content, contributing a delightful fruity aroma with a pear-like sweet-sour taste. Ethyl acetate, ethyl caproate, propionate, and ethyl butyrate showed pineapple, grape, cherry, apple, and other flavors. These ester compounds synergistically interact, conferring a unique fruity aroma to the fruit puree.

The alcohol compounds in compound fruit puree compared to CA puree increased by 12 kinds, and most showed afresh floral and grassy scents. In the S sample, only 2-methyl-1-butanol (0.29%) was increased. The M sample increased 2-methyl-1-butanol (0.25%) and furfuryl alcohol (0.37%), while the G sample increased 2-methyl-1-butanol (0.16%), 2-octanol (1.01%), 2-methyl-2-hexanol (1.03%), and 2-ethylhexanol (1.02%). Adding two sugars to the composite fruit puree only increased S-(-)-2-methyl-1-butanol (0.26%, 0.27% and 0.24%). Complex puree with three added sugars increased isoamyl alcohol (0.14%) and 1-pentanol (0.14%). Newly generated alcohol compounds mainly originate from the transformation of amino acids and the degradation of fatty acids (Dudareva et al., 2013; Liu et al., 2023b).

The content of aldehyde, ketone, and acid compounds in the fruit puree is relatively low, accounting for less than 1% of the total content. Although ketone compounds are present in low amounts, their low odor thresholds mean that even at deficient concentrations, they can exhibit intense aromas (Chen et al., 2019b). Nonanal imparts a waxy odor, and aldehydes can negatively impact the flavor profile of fruit puree (Wang et al., 2023). The newly generated furfural and hydroxyacetone in the M and GMS samples are intermediate products of the MR (Shi et al., 2022). Additionally, VC can degrade to produce C_6 ~ C_9 small molecule aldehydes and furfural under heat and oxygen (Wu et al., 2013).

PCA of fruit puree index

Principal Component Matrix

PCA is a statistical tool that explains differences between samples and extracts additional information from variables. It allows for visual recognition of complex data through dimensionality reduction (Granato et al., 2018). In this analysis, composite fruit purees with different added sugars were considered as sample units. 5 quality indicators (TPC, HMF, VC, BI, reducing sugars) and 9 main flavor components (dodecylmethylcyclohexasiloxane, decamethylcyclopentasiloxane, octamethylcyclotetrasiloxane, hexamethylcyclotrisiloxane, 1-caryophyllene, α-pinene, 2-methylbutyl acetate, hexyl acetate, butyl acetate) were selected as variables. After standardization using the Z-score method, PCA was performed using SPSS, followed by comprehensive scoring of different treated compound fruit purees. Table 2 reveals that the first three PCs have eigenvalues greater than 1, with the first principal component (PC1), second principal component (PC2), and third principal component (PC3) contributing 45.99%, 23.02%, and 18.63% to the total variance, respectively. The cumulative contribution rate reached 87.64%. Therefore, the first three PCs were selected for further analysis, as they represent most of the information regarding fruit puree quality.

Table 2
The variance contribution rate of the principal component of the quality of the fruit puree

Component	Initial eigenvalue	Contribution rate of Variance (%)	Cumulative variance contribution rate (%)
1	6.439	45.99	45.99
2	3.223	23.018	69.009
3	2.608	18.632	87.641

The contribution of each indicator to the PCs can be expressed as a component matrix. It can be seen from Table 3 that PC1 is mainly affected by dodecylmethylcyclohexasiloxane, 2-methylbutyl acetate, and butyl acetate. The load weights are 0.928, 0.918, and 0.913, respectively. These three variables are all aroma components of fruit puree, indicating that aroma is an essential source of information for PC1. PC2 is primarily influenced by TPC, HMF, and VC, and the loading weights were − 0.757,0.786 and 0.728, respectively. These three variables are all related to NEB and were important sources of information for PC2. PC3 is mainly affected by α-pinene.

Table 3
The principal component load matrix of each index of composite fruit puree

Index	PC1	PC2	PC3
TPC	0.494	-0.757	-0.269
HMF	-0.483	0.786	0.237
VC	0.579	0.728	-0.078
BI	-0.22	0.643	0.414
Reducing sugar	0.769	-0.224	-0.512
Dodecamethyl cyclohexasiloxane	0.928	0.051	0.21
Decamethyl cyclopentasiloxane	0.758	0.033	-0.628
Octamethylcyclotetrasiloxane	-0.823	0.156	-0.494
Hexamethylcyclotrisiloxane	-0.761	-0.18	0.174
1-Caryophyllene	0.107	-0.694	0.61
α-Pinene	-0.008	-0.403	0.848
2-Methylbutyl acetate	0.918	0.111	0.316
Hexylacetate	0.779	0.556	0.177
Butyl acetate	0.913	0.111	0.326

Model construction and principal component scores

The expressions for the three PCs are constructed by calculating the coefficient values of the feature vectors:

$$F_1 = 0.1947ZX_1 - 0.1903ZX_2 + 0.2282ZX_3 - 0.0867ZX_4 + 0.3031ZX_5 + 0.3657ZX_6 + 0.2987ZX_7 - 0.3243ZX_8 - 0.2999ZX_9 + 0.0422ZX_{10} - 0.0032ZX_{11} + 0.3618ZX_{12} + 0.3070ZX_{13} + 0.3598ZX_{14}$$

$$F_2 = -0.4217ZX_1 + 0.4378ZX_2 + 0.4055ZX_3 + 0.3582ZX_4 - 0.1248ZX_5 + 0.0284ZX_6 + 0.0184ZX_7 + 0.0869ZX_8 - 0.1003ZX_9 - 0.3866ZX_{10} - 0.2245ZX_{11} + 0.0618ZX_{12} + 0.3097ZX_{13} + 0.0618ZX_{14}$$

$F_3 = -0.1666ZX_1 + 0.1468ZX_2 - 0.0483ZX_3 + 0.2564ZX_4 - 0.3170ZX_5 + 0.1300ZX_6 - 0.3889ZX_7 - 0.3059ZX_8 + 0.1077ZX_9 + 0.3777ZX_{10} + 0.5251ZX_{11} + 0.1957ZX_{12} + 0.1096ZX_{13} + 0.2019ZX_{14}$

In the above expressions, F_1, F_2, and F_3 represent the weight values of PC1, PC2, and PC3, respectively. ZX_1 to ZX_{14} represent the standardized values of variables (TPC, HMF, VC, BI, reducing sugars, dodecamethyl cyclohexasiloxane, decamethyl cyclopentasiloxane, octamethylcyclotetrasiloxane, hexamethylcyclotrisiloxane, 1-caryophyllene, α-pinene, 2-methylbutyl acetate, hexylacetate, butyl acetate). Then, a comprehensive evaluation function is obtained using the contribution rates of each principal component as weights: $Y = 0.5248F_1 + 0.2626F_2 + 0.2126F_3$.

From Table 4, the S sample scores were highest in both PC1 comprehensive value F_1 and PC2 comprehensive value F_2, indicating that PC1 and PC2 significantly impact compound fruit purees with added sucrose. The GS sample score was the highest in the PC3 comprehensive value F_3, which indicated that PC3 greatly influenced on the compound puree added with sucrose and maltose. The top four rankings in comprehensive scores are S, GS, M, and GM samples, all of which have scores higher than the average, suggesting that the composite fruit puree with added sucrose has better overall quality than others.

Table 4
PCA comprehensive score of compound fruit puree added with different sugar

Sample	F_1	F_2	F_3	Synthesis score (Y)	Rank
S	2.52	2.85	-0.18	2.03	1
M	1.9	-0.31	-2.34	0.42	3
G	-3.98	1.7	0.39	-1.56	6
MS	-0.31	-1.77	1.82	-0.24	5
GS	1.11	0.45	1.98	1.12	2
GM	1.69	-2.04	-0.01	0.35	4
GMS	-2.93	-0.88	-1.66	-2.12	7

Conclusion

This study investigated the effects of different sugar types on the quality of composite CA puree before and after storage. The study investigated the effects of different sugar additives on the quality of stored compound CA puree. It was found that the type of sugar had no significant effect on the TPC in the puree ($p > 0.05$) but had a significant effect on HMF content, VC content, BI, pH, and reducing sugar content ($p < 0.05$). Analysis of changes in various indicators suggests that phenolic compounds contribute little to NEB in the early stages of fruit puree storage, and the degradation of VC may be the primary mechanism of NEB.

Aroma composition analysis showed that the contribution of sweeteners to flavor substances, from highest to lowest, is glucose, maltose, and sucrose. PCA results indicated that the top four rankings in comprehensive scores were S, GS, M, and GM sample. This result is essential for meeting different processing requirements for CA products.

Abbreviations

CA	*Choerospondias axillaris*
NEB	Non-enzymatic browning
MR	Maillard reaction
TPC	Total phenolic content
HMF	5-Hydrxymethylfurfural
BI	Browning index
VC	Vitamin C
PCs	Principal components
PCA	Principal component analysis

Declarations

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Conflict of Interest

All authors declare no conflicts of interest.

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Figures

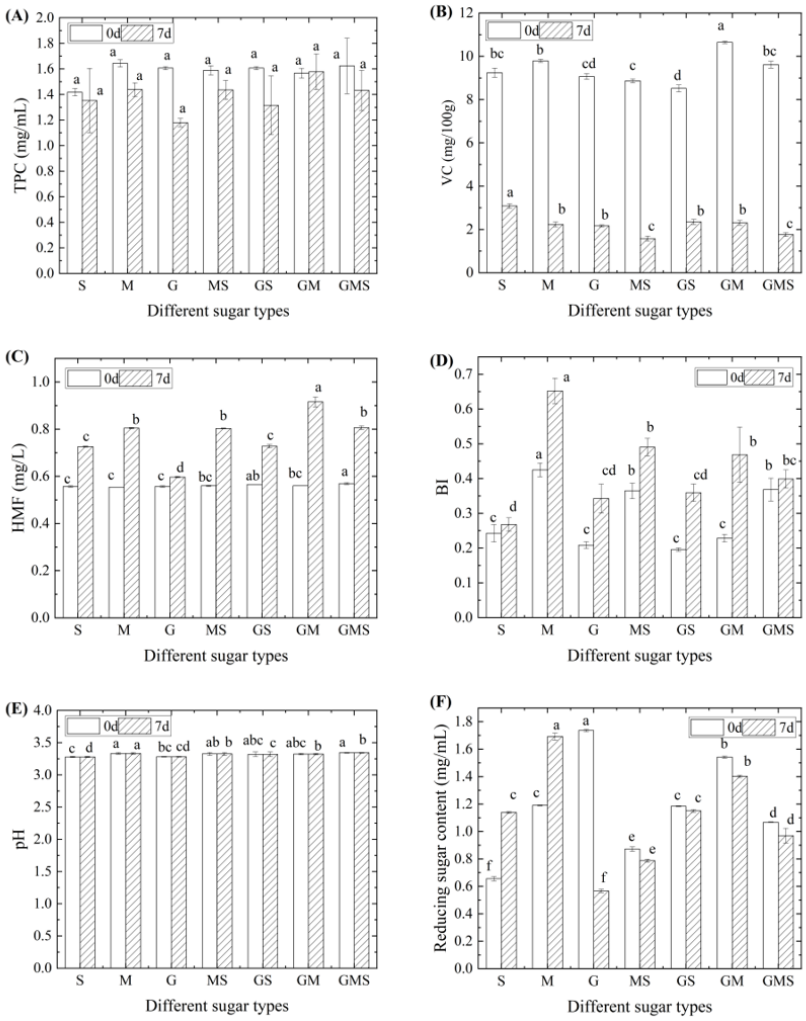


Figure 1

Changes in total phenols content (TPC, **A**) , vitamin c content (VC, **B**), 5-hydroxymethyl furfural content (HMF, **C**), browning index (BI, **D**), pH (**E**), reducing sugars content (**F**) before and after storage of fruit puree.

Different letters in the graph indicate significant differences between samples using Waller-Duncan's multiple range test at $p < 0.05$