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Sugars and organic acids components of different provenances *Choerospondias axillaries* fruit

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Abstract: *Choerospondias axillaries* (*CA*) is an important fast-growing afforestation tree species in southern China, and its fruit has medicinal and edible value. High performance liquid chromatography was used to determine the composition and content of sugar and acid in *CA* fruits from different provenances, and cluster analysis was conducted on different provenances. The results showed that the total sugar content of *CA* fruit ranged from 49.31 to 139.41 mg/g, with sucrose accounting for the highest proportion of total sugar, followed by glucose, and fructose was the lowest. The total acid content of *CA* fruit ranged from 47.97 to 82.81 mg/g, with citric acid accounting for 67.09% of the total acid, followed by ascorbic acid, quinic acid, tartaric acid and malic acid. Cluster analysis was conducted on 20 *CA* fruits, which were divided into 4 categories. It was recommended to develop N19 fruit had the highest content of sucrose and glucose, and the highest sweetness value, sugar-acid ratio and sweet-acid ratio. It can be suggested to be developed as a high-sugar fresh food source. N02 fruit with high sugar and high acid content can be used as a raw material for fruit cake processing. This result provides an important reference for the quality evaluation and rational development and utilization of *CA.*

Keywords: *Choerospondias axillaries*; u

Choerospondias axillaries (Roxb.) Burtt et Hill. (*CA*) is widely grown in southern China, and also found in Nepal, Japan and India. As an important fast-growing afforestation tree species in subtropical regions of China, *CA* tree has good ecological effects, and its fruits can also generate certain economic value (Liu et al. 2020; You et al. 2020). The *CA* fruit is a food with medicinal and edible homology. The dried fruit can be a traditional Mongolian medicine called 'Choerospondiatis Fructus'. The major chemical components of Choerospondiatis Fructus include phenolic acids, flavonoids, sterols, organic acids, and others (Li et al. 2017). As a food product, *CA* fruit is rich in nutrients such as organic acid, pectin, vitamin C, and mineral elements (Li et al. 2015). It can be eaten fresh or processed into fruit cakes, fruit wine, fruit vinegar, etc (Dantong et al. 2021, Jaing et al. 2021). The composition and content of organic acids in fruits are important factors determining fruit quality and flavor formation. The sweetness and acidity of sugar and acid components are different, and their content, types, and ratio jointly affect the formation

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of flavor. Sugar and acid flavor is also an important reference for evaluating fruit quality and cultivation techniques such as germplasm resources, new variety selection, hybrid offspring (Matsumoto et al. 2012). Sugar is also involved in the biosynthesis of polyphenols, and the higher sugar content in fruits means a higher concentration of polyphenols. Therefore, from the perspective of a nutritious diet, it is also very important. Organic acids can also stabilize anthocyanins, extend the shelf life of fresh fruits and processed products, and play an important role in apple coloring (Guan et al. 2015). The proportion of sugar and acid composition varies among different varieties (Clements. 2006; Zheng et al. 2020). Hayaloglu et al. (2015) showed there are significant differences in chemical composition among different cherry varieties. Bu et al. (1992) found that the organic acid content and total sugar content in the fresh *CA* fruit were 2.46% and 7.85%, respectively. Liu et al. (2000) further analyzed the organic acid components in *CA* fruit by high-performance liquid chromatography. The results showed that *CA* fruit contains 21 types of organic acids, with citric acid, tartaric acid, and malic acid as the main components, with a total organic acid content ranging from 5.22% to 8.13%. Li et al. (2015) found that there are mainly 7 types of organic acids in the *CA* fruit, with citric acid and malic acid as the main organic acids. The total amount of organic acids in the flesh and skin of *CA* fruit is similar, and blanching treatment during the cake production process causes significant organic acid loss.

At present, there is no report on the evaluation of the sugar and acid components and sweet and sour flavor characteristics of *CA* fruit from different sources. Therefore, this study will take 20 sources of *CA* fruit as the research object, and use the HPLC method to determine the sugar and acid composition and content of the fruits, indicators such as evaluate the sweetness value, sweet acid ratio, and sugar acid ratio, and conduct clustering analysis. Clarify the characteristics of sugar and organic acid components in the fruits of different sources of *CA* fruit, in order to provide a reference basis for variety selection and promotion in the development of *CA* industry.

MATERIAL AND METHODS

Plant materials and experimental procedure. The mature *CA* fruit were obtained from the Science and Technology Park of Jiangxi Agricultural University (Nanchang, China) between August and September 2020.

The park has a moist subtropical monsoon climate with sufficient light and rainfall. The soil type is red loam, slightly acidic, with substantial fertility and good drainage. All the trees were randomly planted in the experimental plot in 2010 with a row spacing of 3.0 m × 3.0 m. The trees showed vibrant growth. The experiment design was a fully randomized model. The information of 20 provenances is shown in Table 1 and Supplementary Material Figure 1 (ESM). The fruits were kept in iceboxes, transported to the laboratory, and analyzed relevant indicators the same day. Then the pulp was frozen in liquid nitrogen and stored in a –80 °C freezer for sugar and organic acid content determination. Each provenances of 30 fruits in a group, repeated three times.

Determination method

Extraction of sugar and acid components. The extraction of fruit sugar and acid components was carried out according to the method of Gao et al. (2018). Accurately weigh 2.00 g of frozen *CA* pulp powder by analytical balance AP135W (Shimadzu, Japan) with accuracy of ± 0.001 g, add 8 mL of 80% ethanol, and then take a constant temperature water bath at 35 °C for 20 minutes by Electro-Thermostatic water bath (Shanghai Boxun Medical Biological Instrument Co., Ltd, China). After the water bath was completed, centrifuge at 10 000 r/min for 20 minutes at room temperature. Take the supernatant, repeat the extraction three times, and merge the extracted supernatant to a constant volume of 25 mL. Take 1 mL of the extraction solution, concentrate and dry it by vacuum Centrifugal Concentrator 5301 Plus (Eppendorf Concentrator, USA), then add 1 mL of ultrapure water to dissolve for later use.

Determination of sugar components. The determination of sugar content followed the method of Sun et al. (2012). Filter the sample in 2.2.1 using a filter membrane (pore size 0.45 μm) by high performance liquid chromatography (HPLC) (Shimadzu Japan). The chromatographic conditions was: waters NH_2 column (4.6 mm × 250 mm, 5.0 μm); the temperature of the detection pool was 30 °C; the mobile phase was V (acetonitrile): V (water) = 75 : 25; flow rate 1.0 mL/min; injection volume 20 μL; refractive index detector (RID) differential detector detection.

https://doi.org/10.17221/128/2023-HORTSCI

Table 1. The geographical location of different provenances of *Choerospondias axillaris*

Provenance number	Provenance	Provenance number	Provenance
N01	Shixing County, Guangdong Province	N11	Jinshi City, Hunan Province
N02	Chatan, Chongyi County, Jiangxi Province	N12	Zigui County, Hubei Province
N03	Huichang, Jiangxi Province	N13	Ridu, Chongyi County, Jiangxi Province
N04	Chongren, Jiangxi Province	N14	Longquan City, Zhejiang Province
N05	Qianshan, Shangrao City, Jiangxi Province	N15	Guilin County, Guangxi Province
N06	Huludong, Ganzhou City Jiangxi Province	N16	Guiyang City, Guizhou Province
N07	Nanping City, Fujian Province	N17	Yangshuo, Guilin County, Guangxi Province
N08	Yiyang City, Hunan Province	N18	Yiyang County, Hunan Province
N09	Hezhou City, Guangxi Province	N19	Nanchang, Jiangxi Province
N10	Changde City, Hunan Province	N20	Wanzai County, Jiangxi Province

Determination of organic acid components. The determination of organic acid components was carried out according to the method of GAO et al. (2018) by HPLC (Shimadzu, Japan). Apply the sample in 1.2.1 to a microporous filter membrane (pore size 0.22 μm) filter. The chromatographic conditions was as follows: C18 column (4.6 mm × 250 mm, 5.0 μm); the temperature of the detection pool was 25 °C; the mobile phase was 50 mmol/L hydrogen phosphate diamine (pH = 2.7); the flow rate was 0.5 mL/min; Injection volume 20 μL; detected using a diode array detector.

Sweetness value, sugar-acid ratio, sweet-acid ratio. Based on the determination of sucrose sweetness as 1.0, the values of fructose and glucose are set to 1.75 and 0.7, and the sweetness value is calculated according to Formula 1. The total sugar, total organic acid content, sugar to acid ratio, and sweet to acid ratio are calculated according to Formula 2–5, respectively.

Data Analysis

Sweetness value = fructose content × 1.75 + sucrose content × 1.0 + glucose content × 0.7 (1)

Total sugar content = sucrose content + glucose content + fructose content (2)

Total acid content = oxalic acid content + tartaric acid content + quinic acid content + malic acid content + ascorbic acid content + citric acid content + succinic acid content + fumaric acid content + aconitic acidcontent (3)

Sugar acid ratio = total sugar content ÷ total acid content (4)

Sweet acid ratio = sweetness value ÷ total acid content (5)

Microsoft Excel 2010 software (Office 2010, USA) was used for data statistics and chart drawing, Results were expressed as the mean ± standard error. SPSS 20.0 statistical software (IBM SPSS Statistics, USA) was used for difference significance analysis, and cluster analysis. The significant differences were determined using Duncan's new multiple range test. Statistical significance was considered at $P < 0.05$. The cluster were determined using system clustering algorithm.

RESULTS AND ANALYSIS

Organic Acid Content of *CA* Fruits from Different Provenances. Nine organic acid components were determined in *CA* fruit (Table 2, Figure 1). Among the 9 organic acids determined, citric acid content was the highest, with its ratio to total acid exceeding 50.00%, followed by ascorbic acid, quinic acid, malic acid, and tartaric acid. The ratios of ascorbic acid, quinic acid, malic acid, and tartaric acid to total acid were higher, reaching 26.14%, 15.27%, 12.67%, and 8.66%, respectively. The content of oxalic acid, aconitic acid, and succinic acid was relatively low, and the highest content of the three in *CA* fruits does not exceed 0.50 mg/g. The content of fumaric acid was the lowest, with an average of only 0.06 mg/g.

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Table 2. The concentrations of organic acids in *CA* fruit from different provenances (mean ± SE)

Provenance number	Oxalic acid (mg/g)	Tartaric acid (mg/g)	Quinic acid (mg/g)	Malic acid (mg/g)	Ascorbic acid (mg/g)	Citric acid (mg/g)	Succinic acid (mg/g)	Fumaric acid (mg/g)	Aconitic acid (mg/g)	Total organic acids (mg/g)
N01	0.43 ± 0.00^{a}	1.54 ± 0.01^{j}	8.06 ± 0.01^{cd}	1.25 ± 0.04^{e}	6.67 ± 0.25^{hijk}	57.32 ± 2.56^{a}	0.12 ± 0.03^{bcde}	0.09 ± 0.02^{ab}	0.16 ± 0.00^{a}	75.63 ± 2.29^{b}
N02	0.13 ± 0.00^{i}	1.73 ± 0.02^{i}	8.18 ± 0.12^{c}	5.87 ± 0.25^{c}	20.31 ± 0.83^{b}	46.27 ± 0.01^{ef}	0.13 ± 0.04^{ab}	0.05 ± 0.00^{cdef}	0.12 ± 0.00^{e}	82.81 ± 0.99^{a}
N03	0.10 ± 0.00^{l}	2.52 ± 0.02^{ef}	7.93 ± 0.05^{d}	4.11 ± 0.33^{d}	0.45 ± 0.03^{l}	38.64 ± 0.12^{hi}	0.12 ± 0.01^{bcd}	0.01 ± 0.01^{g}	0.11 ± 0.00^{f}	53.97 ± 0.42^{h}
N04	0.15 ± 0.01^{g}	1.91 ± 0.02^{h}	7.55 ± 0.11^{e}	8.09 ± 0.09^{b}	13.58 ± 0.92^{c}	33.08 ± 0.08^{k}	0.10 ± 0.00^{cde}	0.03 ± 0.00^{efg}	0.13 ± 0.00^{d}	64.62 ± 0.65^{e}
N05	0.11 ± 0.01^{k}	3.88 ± 0.02^{b}	7.32 ± 0.11^{f}	4.21 ± 0.09^{d}	0.90 ± 0.02^{l}	31.29 ± 0.05^{k}	0.10 ± 0.00^{cde}	0.02 ± 0.01f^{g}	0.13 ± 0.00^{d}	47.97 ± 0.18^{i}
N06	0.25 ± 0.01^{b}	5.15 ± 0.23^{a}	9.31 ± 0.28^{b}	4.05 ± 0.14^{d}	21.50 ± 1.10^{a}	41.73 ± 1.51^{g}	0.09 ± 0.01^{e}	0.04 ± 0.00^{defg}	0.14 ± 0.00^{c}	82.26 ± 3.24^{a}
N07	0.14 ± 0.01^{h}	2.50 ± 0.27^{efg}	9.80 ± 0.08^{a}	9.09 ± 0.07^{a}	11.00 ± 0.18^{de}	38.94 ± 0.14^{hi}	0.10 ± 0.00^{de}	0.05 ± 0.00^{cdef}	0.15 ± 0.00^{b}	71.76 ± 0.46^{c}
N08	0.12 ± 0.00^{j}	2.55 ± 0.02^{e}	5.96 ± 0.18^{kl}	1.04 ± 0.02^{fgh}	5.95 ± 0.29^{jk}	46.99 ± 0.24^{def}	0.09 ± 0.01^{e}	0.06 ± 0.02^{bcd}	0.15 ± 0.00^{b}	62.91 ± 0.33^{e}
N09	0.09 ± 0.00^{m}	3.51 ± 0.02^{c}	5.93 ± 0.06^{kl}	0.69 ± 0.06^{jk}	5.70 ± 0.27^{jk}	40.59 ± 0.27^{gh}	0.10 ± 0.02^{cde}	0.05 ± 0.01^{cdef}	0.13 ± 0.00^{d}	56.80 ± 0.11^{g}
N10	0.18 ± 0.00^{e}	2.36 ± 0.01f^{g}	6.20 ± 0.04^{ij}	0.90 ± 0.05^{ghi}	6.92 ± 0.28^{hij}	51.34 ± 4.34^{c}	0.13 ± 0.02^{abc}	0.08 ± 0.01^{abc}	0.13 ± 0.00^{d}	68.24 ± 4.64^{d}
N11	0.20 ± 0.00^{d}	2.55 ± 0.01^{e}	6.83 ± 0.02^{g}	0.85 ± 0.02^{hij}	7.92 ± 0.14^{h}	54.73 ± 0.18^{b}	0.11 ± 0.00b^{cde}	0.06 ± 0.01^{bcd}	0.13 ± 0.00^{d}	73.38 ± 0.08b^{c}
N12	0.10 ± 0.00^{lm}	3.28 ± 0.01^{d}	5.86 ± 0.05^{l}	0.90 ± 0.08^{ghj}	6.53 ± 0.25^{ijk}	35.88 ± 0.09^{j}	0.10 ± 0.00^{cde}	0.06 ± 0.00^{bcd}	0.13 ± 0.00^{d}	52.84 ± 0.48^{h}
N13	0.09 ± 0.00^{m}	2.44 ± 0.05^{efg}	5.41 ± 0.05^{m}	0.72 ± 0.06^{ijk}	5.39 ± 2.35^{k}	42.41 ± 1.53^{g}	0.09 ± 0.01^{e}	0.06 ± 0.00^{bcd}	0.14 ± 0.00^{c}	56.75 ± 0.91^{g}
N14	0.24 ± 0.00^{c}	5.08 ± 0.01^{a}	6.07 ± 0.01^{jk}	0.94 ± 0.01^{gh}	7.75 ± 0.14^{hi}	38.28 ± 0.01^{i}	0.11 ± 0.00^{bcde}	0.08 ± 0.01^{abc}	0.14 ± 0.00^{c}	58.69 ± 0.16f^{g}
N15	0.11 ± 0.00^{k}	2.59 ± 0.00^{e}	6.51 ± 0.02^{h}	1.08 ± 0.04^{efg}	14.03 ± 0.47^{c}	47.67 ± 0.45^{de}	0.11 ± 0.00^{bcde}	0.08 ± 0.00^{abc}	0.15 ± 0.00^{b}	72.32 ± 0.18^{c}
N16	0.10 ± 0.00^{l}	2.34 ± 0.01^{g}	6.27 ± 0.01^{i}	1.16 ± 0.02^{ef}	9.65 ± 0.21^{fg}	48.70 ± 0.27^{d}	0.15 ± 0.02^{a}	0.08 ± 0.01^{abc}	0.14 ± 0.00^{c}	68.60 ± 0.38^{d}
N17	0.15 ± 0.00^{g}	0.74 ± 0.01^{l}	5.97 ± 0.08^{kl}	0.70 ± 0.07^{ijk}	11.54 ± 0.47^{d}	40.71 ± 0.14^{gh}	0.12 ± 0.00^{bcd}	0.08 ± 0.04^{abc}	0.14 ± 0.00^{c}	60.15 ± 0.61^{f}
N18	0.16 ± 0.01^{f}	1.07 ± 0.02^{k}	4.56 ± 0.06^{n}	0.62 ± 0.10^{k}	9.81 ± 0.82^{efg}	35.14 ± 0.15^{j}	0.10 ± 0.01^{cde}	0.07 ± 0.05^{abcd}	0.11 ± 0.00^{f}	51.65 ± 1.18^{h}
N19	0.12 ± 0.00^{j}	1.42 ± 0.03^{j}	5.45 ± 0.04^{m}	0.61 ± 0.03^{k}	9.34 ± 0.09^{g}	42.50 ± 0.17^{g}	0.10 ± 0.00^{de}	0.08 ± 0.03^{abc}	0.14 ± 0.00^{c}	59.76 ± 0.38^{f}
N20	0.08 ± 0.00^{n}	1.82 ± 0.22^{hi}	5.90 ± 0.02^{kl}	0.89 ± 0.03^{ghij}	10.83 ± 0.48^{def}	45.41 ± 0.13^{f}	0.12 ± 0.01^{bcd}	0.11 ± 0.03^{a}	0.15 ± 0.00^{b}	65.31 ± 0.34^{e}
Mean	0.15	2.55	6.75	2.39	9.29	42.88	0.11	0.06	0.14	64.32
CV (%)	53.11	45.76	20.02	109.8	57.1	16.21	13.96	39.12	9.32	15.47

$^{a-n}$Significant differences at $P < 0.05$; values are means ± SD; CV – coefficient of variation

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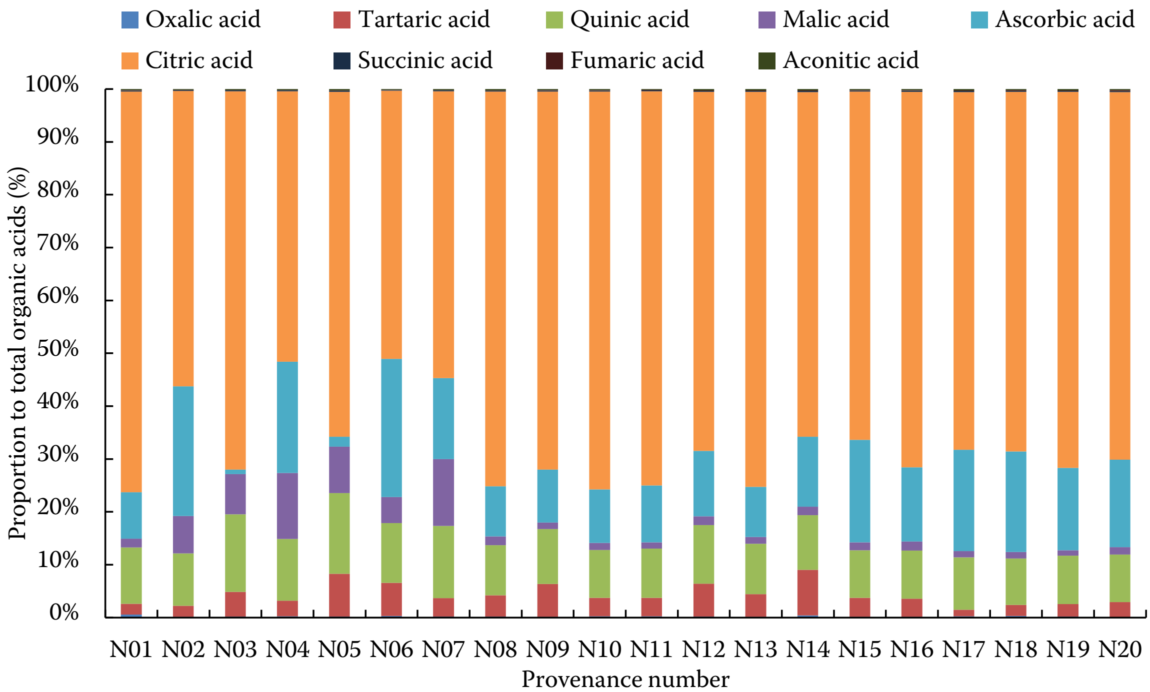

Figure 1. The proportion of organic acid component in *Choerospondias axillaries* fruits from different provenances

The citric acid content among various sources ranged from 31.28 to 57.31 mg/g, with an average value of 42.88 mg/g, the coefficient of variation was 16.21%. N01 fruit had the highest citric acid content, followed by N10 and N11 fruit, which all had a citric acid content exceeding 50 mg/g. N05 fruit had the lowest citric acid content, only 31.29 mg/g. The content of ascorbic acid among various sources ranged from 0.45 to 21.50 mg/g, with an average value of 9.29 mg/g and a coefficient of variation of 57.10%. The ascorbic acid of N06 fruit was highest, while N03 fruit was the lowest. The content of quinic acid among various sources ranges from 4.56 to 9.80 mg/g, with an average value of 6.75 mg/g and a coefficient of variation of 20.02%. The quinic acid content of N07 fruit was higher, while that of N18 was the lowest. The malic acid content among various sources ranges from 0.61 to 8.09 mg/g, with an average value of 2.39 mg/g. The coefficient of variation was the highest, reaching 109.80%. The N04 fruit malic acid content was the highest, while N19 was the lowest. The tartaric acid content among various sources ranges from 0.74 to 5.08 mg/g, with an average value of 2.55 mg/g and a coefficient of variation of 45.76%. The fruit of N06 was the highest, while the N17 fruit of was the lowest. Among 20 provenances *CA* fruit, the average contents of oxalic acid, aconitic acid, and succinic acid were 0.15 mg/g, 0.14 mg/g, and 0.11 mg/g, respectively, with coefficients of variation of 53.11%, 9.32%, and 13.96%. Among them, the fruit of N01 had the highest contents of oxalic acid and aconitic acid (0.43 mg/g, 0.15 mg/g, respectively), and the N10 fruit had the highest content of succinic acid (0.13 mg/g). The content of fumaric acid was the lowest, with fumaric acid content only ranging from 0.01 to 0.11 mg/g.

The total organic acid content of 20 provenances *CA* fruit ranged from 47.97 to 82.81 mg/g, with an average of 64.32 mg/g and a coefficient of variation of 15.47%. Among them, N02 fruithad the highest total organic acid content at 82.81 mg/g, while N06 and N01 had relatively high total organic acid content at 82.26 mg/g and 75.63 mg/g, respectively. However, N03, N05, N09, N12, N13, N14, N18, and N19 had relatively low total organic acid content, not exceeding 60.00 mg/g, the total organic acid content in of N05 was the lowest.

Sugar Content of *CA* Fruit from Different Provenances. The average total sugar content of *CA* fruit was 77.87 mg/g, with a coefficient of variation of 29.21%. There was a significant difference in total sugar content among different provenances fruits (Table 3 and Figure 2). Among them, the total sugar content in N19 fruit was highest, reaching 139.41 mg/g. N15 fruit had the lowest total

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Table 3. The sugar component content, sweetness value, sugar-acid ratio and sweet-acid ratio in *Choerospondias axillaries* fruit from different provenances (mean ± SE)

Provenance number	Sucrose (mg/g)	Fructose (mg/g)	Glucose (mg/g)	Total sugar (mg/g)	Sweetness value	Sugar - acid ratio	Sweet-acid ratio
N01	30.17 ± 1.78^{h}	6.67 ± 0.40^{g}	41.03 ± 1.85^{b}	77.87 ± 2.84^{e}	72.61 ± 2.71^{e}	1.03 ± 0.01^{ij}	0.96 ± 0.01^{i}
N02	75.20 ± 4.13^{a}	7.51 ± 0.31^{fg}	38.34 ± 2.74^{bc}	121.04 ± 6.62^{b}	117.09 ± 6.23^{b}	1.46 ± 0.09^{cd}	1.41 ± 0.09^{de}
N03	53.28 ± 4.04^{c}	6.36 ± 0.71^{g}	39.72 ± 3.72^{b}	99.36 ± 1.82^{c}	94.2 ± 2.84^{cd}	1.84 ± 0.02^{b}	1.75 ± 0.04^{c}
N04	62.26 ± 6.87^{b}	6.82 ± 0.13^{g}	17.15 ± 2.43^{fg}	86.24 ± 9.42^{d}	87.07 ± 8.90^{c}	1.33 ± 0.14^{def}	1.35 ± 0.13^{e}f
N05	40.16 ± 4.78^{efg}	6.89 ± 0.01^{g}	9.29 ± 2.47^{h}	56.34 ± 6.76^{ijk}	59.19 ± 6.24^{fg}	1.17 ± 0.14^{gh}	1.23 ± 0.13^{fg}
N06	24.34 ± 2.33^{hij}	10.09 ± 0.69^{d}	18.23 ± 1.11^{fg}	52.66 ± 1.61^{jk}	55.67 ± 1.43^{g}	0.64 ± 0.04^{l}	0.68 ± 0.04^{j}
N07	50.95 ± 4.51^{cd}	8.94 ± 0.30^{de}	8.43 ± 1.34^{h}	68.32 ± 3.57^{fgh}	72.92 ± 4.04^{e}	0.95 ± 0.06^{jk}	1.02 ± 0.06^{hi}
N08	38.32 ± 4.20^{fg}	9.04 ± 1.85^{de}	21.74 ± 2.71^{ef}	69.10 ± 5.18^{efgh}	70.44 ± 5.35^{e}	1.10 ± 0.08^{hi}	1.12 ± 0.08^{gh}
N09	45.07 ± 4.15^{def}	8.94 ± 0.30^{de}	34.60 ± 3.65^{c}	88.62 ± 7.96^{d}	86.67 ± 7.23^{c}	1.56 ± 0.14^{c}	1.53 ± 0.13^{d}
N10	38.72 ± 3.27^{efg}	8.49 ± 0.97^{ef}	18.09 ± 4.76^{fg}	65.30 ± 4.46^{fghi}	67.14 ± 4.45^{ef}	0.96 ± 0.02^{jk}	0.98 ± 0.01h^{i}
N11	36.86 ± 7.91^{g}	9.04 ± 0.34^{de}	17.44 ± 3.03^{fg}	63.33 ± 10.96^{fgh}	65.75 ± 10.49^{ef}	0.86 ± 0.15^{k}	0.90 ± 0.14^{i}
N12	25.36 ± 2.31^{hij}	6.36 ± 0.41^{g}	29.89 ± 3.69^{d}	61.61 ± 3.50^{ghij}	58.91 ± 2.79^{fg}	1.17 ± 0.06^{gh}	1.12 ± 0.04g^{h}
N13	22.32 ± 3.48^{j}	7.51 ± 0.09^{fg}	42.79 ± 3.51^{b}	72.61 ± 6.29^{ef}	67.55 ± 5.45^{ef}	1.28 ± 0.12^{efg}	1.19 ± 0.11^{g}
N14	38.12 ± 2.56^{g}	6.86 ± 0.32^{g}	25.57 ± 3.69^{e}	70.55 ± 1.15^{efgh}	69.30 ± 0.78^{e}	1.20 ± 0.02fg^{h}	1.18 ± 0.02^{g}
N15	23.14 ± 2.69^{ij}	9.40 ± 0.26^{de}	16.76 ± 0.40^{g}	49.31 ± 2.77^{k}	52.17 ± 2.49^{g}	0.68 ± 0.04^{l}	0.72 ± 0.03^{j}
N16	30.00 ± 0.89^{h}	15.73 ± 0.87^{b}	15.27 ± 0.68^{g}	61.00 ± 2.17^{ghij}	68.98 ± 2.68^{e}	0.89 ± 0.03^{jk}	1.01 ± 0.03^{h}i
N17	42.29 ± 1.39^{efg}	8.95 ± 1.00^{de}	19.92 ± 0.79^{fg}	71.16 ± 2.34^{efg}	72.89 ± 2.74^{e}	1.18 ± 0.03^{gh}	1.21 ± 0.03^{g}
N18	45.41 ± 1.29^{de}	14.51 ± 0.02^{c}	34.63 ± 1.88^{c}	94.55 ± 2.48^{cd}	96.78 ± 2.10^{c}	1.83 ± 0.05^{b}	1.87 ± 0.05^{b}
N19	78.85 ± 1.49^{a}	7.18 ± 1.20^{g}	53.38 ± 1.55^{a}	139.41 ± 0.74^{a}	131.45 ± 0.83^{a}	2.33 ± 0.02^{a}	2.20 ± 0.01^{a}
N20	29.71 ± 0.15^{hi}	24.71 ± 1.00^{a}	34.53 ± 1.72^{c}	88.95 ± 0.64^{d}	98.85 ± 0.54^{c}	1.36 ± 0.01^{de}	1.51 ± 0.01^{d}
Mean	41.53	9.5	26.84	77.87	78.28	1.24	1.25
CV (%)	38.79	45.82	46.33	29.21	26.45	33.35	30.61

$^{a–j}$Significant differences at $P < 0.05$; values are means ± SD; CV – coefficient of variation

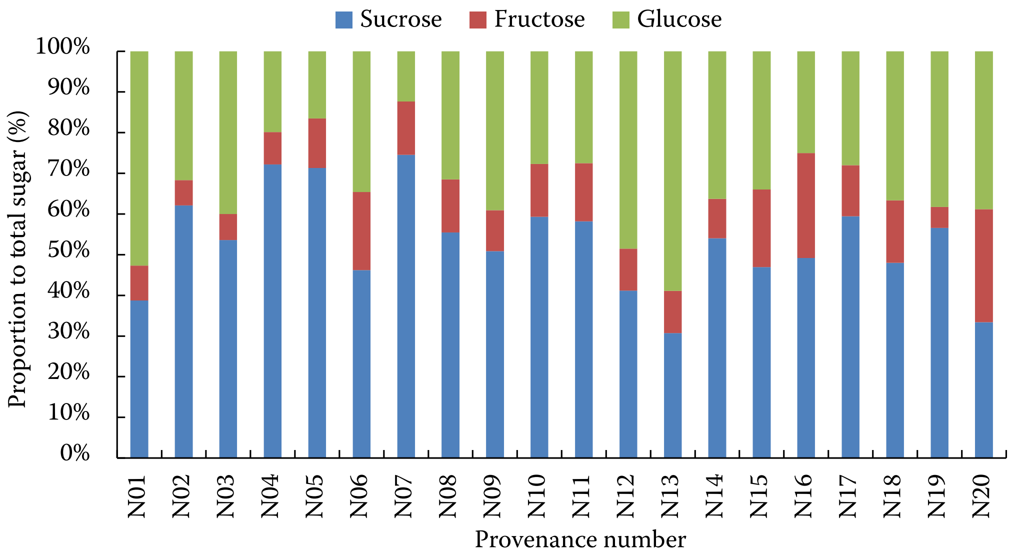

Figure 2. The proportion of sugar component in *Choerospondias axillaries* fruits from different provenances

sugar content, only 49.31 mg/g. The sucrose content of 20 provenances fruits ranged from 22.32 mg/g to 78.85 mg/g, with an average value of 41.53 mg/g and a coefficient of variation of 38.79%. Among them, N19 fruit had the highest sucrose content, and N02 and N04 fruits also had higher sucrose content

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at 75.20 mg/g and 62.26 mg/g, respectively. But N13 fruit had the lowest sucrose content, only 22.32 mg/g. The fructose content of fruits ranged from 6.36 mg/g to 24.71 mg/g, with an average of 9.50 mg/g; glucose content ranges from 8.43 mg/g to 53.38 mg/g, with an average of 22.84 mg/g. The N20 fruit had the highest fructose content, N03 had the lowest fructose content; N19 fruit had the highest glucose content, and N07 had the lowest fructose content. The ratio of sucrose to total sugar content was 30.73~74.57%, with an average of 53.33%. Among them, the proportion of N04, N05 and N07 fruits was higher than 70.00%. Additionally, the ratio of sucrose to total sugar content in N02, N03, N08, N09 and N10 fruits exceeds 50.0%, indicating that sucrose was the most important sugar component in *CA* fruit. The ratio of fructose to total sugar content was 5.15%–27.78%, with an average of 12.20%. Except for N15 and N20, the ratio of fructose to total sugar content in other fruits was less than 20.00%. The ratio of glucose to total sugar content ranged from 12.35% to 58.93%, with an average of 34.47%. Among them, the ratio of glucose to total sugar content in the N01 and N13 fruits exceed 50%, while the ratio of glucose to total sugar content in N04, N05 and N07 fruits was relatively low, all of which do not exceed 20.00%.

The sweetness value of *CA* fruit ranged from 52.17 to 131.45, with an average value of 78.28 and a coefficient of variation of 26.45%. N19 fruit had the highest sweetness value, while N02, N03, N18, and N20 had also higher sweetness values of 117.09, 94.20, 96.77, and 98.85, respectively. The sugar-acid ratio of fruit was between 0.64 and 2.33, and the sweet-acid ratio was between 0.68 and 2.20. Both coefficients of variation were around 30.00%. The suga-acid ratio and sweet-acid ratio of N19 fruit were the highest, and the sugar-acid ratio and sweet-acid ratio of N03, N09, and N18 fruit were all greater than 1.5. However, the sugar-acid ratio and sweet-acid ratio of N06 and N15 fruit were low, only 0.64 and 0.68, respectively.

Cluster analysis. In order to further explore the differences in sugar and acid content and composition of *CA* fruit from different sources, cluster analysis was conducted on 17 sugar and acid indicators. At a Euclidean square distance of 10, 20 *CA* fruit from different provenances were divided into 4 categories: high sugar and low acid type, high sugar and high acid type, low sugar and high acid type, and low sugar and low acid type (Figure 3). The first type was composed of N19, belonging to the high sugar and low acid type fruit. This type of fruit has high sucrose, glucose, and total sugar content, while low citric acid and total organic acid content. Its total sweetness, sugar acid ratio, and sweet acid ratio are all high. The second type was composed of fruit N02, which belongs to the high sugar and high acid type. This type of fruit had high sucrose, glucose, and total sugar content, as well as high citric acid and total organic acid content. Its total sweetness was high, but the sugar to acid ratio and sweet to acid ratio were both moderate and low. The third type was composed of N03, N04, N09, N18, and N20, with lower sugar content and total sweetness compared to the first and second types of fruits. The content of citric acid and total organic acid was only lower than the second type of fruits, and the sugar to acid ratio and sweet to acid ratio are both higher, only lower than the first type of fruits. The fourth category was the other 13 provenances *CA* fruit, which had low total sugar content, total sweetness, sugar acid ratio, and sweet acid ratio.

DISCUSSION

Organic acids are important nutrients and flavor substances in fruits, and their content can have an impact on the fresh taste, storage resistance, and processing quality of the fruit. Plants can contain/synthesise many different organic acids, but most of them are mainly one or two. According to the types of main organic acids in mature fruits, fruits can be divided into citric acid type fruits such as citrus (Roongruangsri et al. 2012), malic acid type fruits such as apples (Prabha et al. 1990), peaches (Lamikanra et al. 2002), and tartaric acid type fruits such as grapes (Yu et al. 2019). In this study, 9 organic acid components of *CA* fruit were determined, and the results showed that the citric acid content of the 20 provenances fruit was 31.29~53.38 mg/g, accounting for 50.73~75.79% of the total acid content, which was significantly positively correlated with the total acid. This indicates that citric acid was the main organic acid in the mature fruit of *CA*, and the fruit was a citric acid type fruit, which was consistent with previous research results (Liu et al. 2002). In addition to citric acid, the *CA* fruit was also rich in organic acids such as ascorbic acid, quinic acid, malic acid, and tartaric acid. There were significant differences in the organic acid composition of fruits from different provenances. The total

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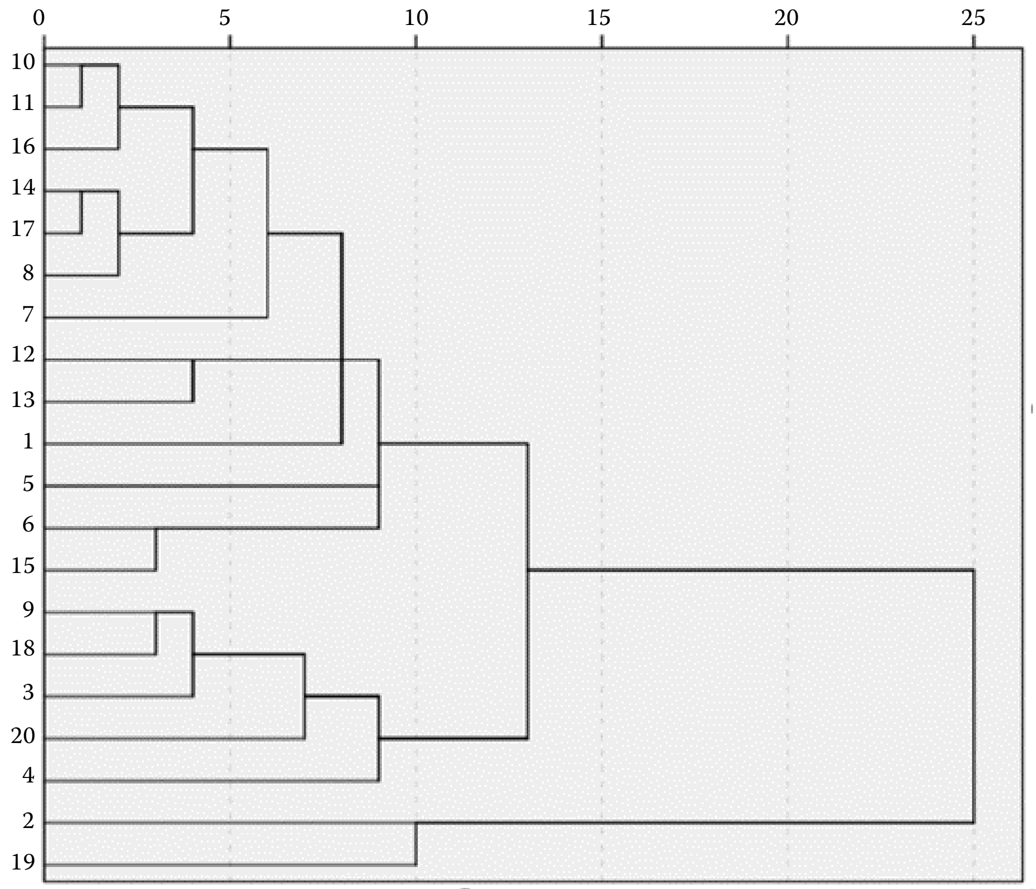

Figure 3. The cluster of *Choerospondias axillaries* fruit from different provenances

organic acid content of N02, N06, and N01 fruits was relatively high, with N01 fruits having the highest citric acid content, followed by N10 and N11 fruits, while N05 fruits had the lowest citric acid content. These results indicated that the provenance could affect the organic acid content of fruits, which was consistent with the research results of Li et al. (2021), which suggests that there is a significant difference in organic acid content among different apple varieties. According to its sugar and acid performance, it can be divided into four types: high sugar and high acid, high sugar and low acid, low sugar and high acid, and low sugar and low acid. In addition to variety and source, development time, cultivation environment, cultivation management techniques, and post harvest treatment can also affect the organic acids in fruits (Priecina et al. 2018; Matsumoto et al. 2021).

Sugar is also an important flavor substance in fruits, and it participates in the metabolic process of multiple substances in fruits (Zhu et al. 2022). The sugar content and sugar component content of fruits are influenced by variety, climate, and cultivation techniques (Liu et al. 2022). The soluble sugars accumulated in *CA* fruit were mainly sucrose, fructose, and glucose. The results showed that there were significant differences in the sugar components of *CA* fruit from different provenances. The total sugar content ranged from 49.31 mg/g to 139.41 mg/g. The N19 fruit had the highest total sugar, sucrose, and glucose content, and belongs to the high sugar type fruit among these 20 provenances.

In order to further comprehensively evaluate the sweet and sour flavor of fruits, researchers not only measured the content of sugar and acid components, but also comprehensively evaluated the sweetness, sugar acid ratio, sweet acid ratio and other indicators of various sugars during the fruit flavor evaluation process (Duan et al. 2020). Analysis of the sweetness value, sugar to acid ratio, and sweet to acid ratio of *CA* fruit showed significant differences. Among them, N19 fruits had the highest sweetness value, sugar to acid ratio, and sweet to acid ratio, while N06 and N15 fruits had relatively small sugar to acid ratio and sweet to acid ratio.

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Cluster analysis is commonly used to measure the similarity between different data sources and classify them into different clusters (Jia et al. 2020). It has been widely used in the analysis of fruit quality (Qiu et al. 2021). In order to further explore the differences in sugar and acid content and composition of *CA* fruit from different sources, cluster analysis was conducted on 17 sugar and acid indicators. At a Euclidean square distance of 10, 20 *CA* fruit from different provenances were divided into 4 categories. The first categorie was composed of N19, belonging to the high sugar and low acid type fruit. Due to its high sweetness value, sugar to acid ratio, and sweet to acid ratio, it can be developed into a fresh food variety for use. The second categorie was composed of fruit N02, which belongs to the high sugar and high acid type. It can be developed into raw materials such as cake and fruit wine for use (Dantong et al. 2021).

CONCLUSION

In this study, the contents and characteristics of sugar and acid components in *CA* fruit from different provenances were investigated. Citric acid was the main organic acid in fruits, followed by ascorbic acid, quinic acid, malic acid, and tartaric acid. The soluble sugars in *CA* fruit include sucrose, fructose, and glucose, with sucrose content accounting for the highest proportion of total sugar, followed by glucose, and fructose accounting for the lowest proportion of total sugar. There were significant differences in organic acid and sugar components among different provenances fruits. Cluster analysis was conducted on 20 *CA* fruit, which were divided into 4 categories. It is recommended to develop N19 fruit has the highest content of sucrose and glucose, and the highest sweetness value, sugar-acid ratio and sweet-acid ratio. It can be suggested to be developed as a high-sugar fresh food source. N02 fruit with high sugar and high acid content can be used as a raw material for fruit cake processing. This result provides an important reference for the quality evaluation and rational development and utilization of *CA*.

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