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Review Article

Distribution and Developmental Characteristics of Sugars and Organic Acids in Fresh Apricots

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Abstract:
This study systematically analyzed the distribution characteristics and developmental patterns of sugars and organic acids in apricots, aiming to explore the accumulation and metabolism of sugars and organic acids. High-performance liquid chromatography was used to determine the sugar and organic-acid contents and distributions in mature apricot fruits from 64 germplasm resources. The results showed that glucose and sucrose are the main sugars in apricots, and the fruits were classified as sucrose-type, or two-sugar-type based on the calculated value of $\log_2$ (glucose/sucrose). Malic and citric acids are the main organic acids in apricots, and the fruits were classified as malic-acid-type, citric-acid-type, or two-acid-type based on the value of $\log_2$ (malic acid/citric acid). During fruit development, glucose content remained high, while fructose and sucrose levels were low but increased during ripening, with sucrose showing the most significant accumulation. Malic acid dominated the organic acid profile during development (accounting for over 90% of the total-organic-acids), but its content decreased during maturation, accompanied by a concurrent increase in citric acid, suggesting a potential link between citric acid levels and fruit ripening. These findings provide a valuable foundation for enhancing the flavor quality of apricot fruits.
Keywords: Apricot fruit; Sugars; Malic-acid-type; Citric-acid-type; Distribution characteristics

1. Introduction

Apricot (*Prunus armeniaca* L.) is highly popular with consumers for its early ripening, excellent flavor, and nutritional value, making it one of the most important fruit crops in China [1, 2]. In 2016, the total apricot-cultivation area for the fresh market and processing in China exceeded 360,000 hectares, with a total yield of 2,700,000 tons [3]. Driven by consumer demand, higher-quality apricots have a greater commodity value. Specifically, sweet apricot varieties with low acidity are more favored by consumers and thus have greater market value. Conversely, sour-tasting apricots have limited economic value.

The taste of a fruit is primarily influenced by the types and contents of sugars and organic acids therein. Sucrose and malic acid are the main sugar and organic acid, respectively, in apples, accounting for over 90% of the total sugar and total acid contents [4]. In citrus fruits, the sugar contents range from 60 to 130 mg·g^{-1} fresh weight (FW), with that of sucrose typically accounting for ~50% of the total. The organic-acid contents in citrus fruits fall in the range 6–11 mg·g^{-1} FW, with malic and citric acid being most abundant [5]. In peaches, which are important drupe fruits, the sugar contents range from 55 to 160 mg·g^{-1} FW, with fructose and glucose being dominant in the young fruit and sucrose becoming dominant upon maturity. The organic-acid contents in peaches fall in the range 4–28 mg·g^{-1} FW, with malic and citric acids being the main components at maturity, the specific contents of which vary depending on cultivar [6]. Plums, another highly cultivated variety of drupe fruits, are mainly Chinese species. Sucrose is the main sugar in plums with a content range of 24.8–152 mg·g^{-1} FW, accounting for over 80% of the total sugars. Malic acid is the main organic acid in plums, with a content range of 11.8–66.38 mg·g^{-1} FW [7].

Apricots are also drupe fruits, and their sugar contents range from 31 to 130 mg·g^{-1} FW. The main sugars in apricots are glucose, sucrose, fructose, and sorbitol, among which sucrose is the dominant component, accounting for over 60% of the total sugar, followed by glucose, while fructose and sorbitol contents are relatively low, accounting for less than 30% of the total. Therefore, apricot fruits are classified as sucrose-type fruits [8, 9]. The organic-acid contents of apricot fruits range from 9.5 to 54 mg·g^{-1} FW, mainly comprising quininic, malic, and citric acids. Of these, quininic acid has the lowest content, accounting for just 2%–12% of the total organic acid, while the combined contents of malic and citric acids account for over 90% of the total organic acids. Currently, the organic acids in apricots classify them as malic-acid-type fruits [10, 11]. However, existing research on sugars and acids in apricot fruits may be subject to inaccuracy due to the limited number of varieties typically studied. Furthermore, there are currently no reported studies on the changes in sugar and organic-acid contents during apricot fruit development [12].

Accordingly, this study employed high-performance liquid chromatography (HPLC) to conduct a detailed analysis of the sugar and organic-acid contents and distribution ratios in mature apricot fruits from a natural population of 332 common apricot seedlings and 64 germplasm resources. Through classification and screening, we selected eight apricot varieties with outstanding characteristics, including sucrose-type and reducing-sugar-type specimens as well as malic-acid-type, citric-acid-type, and two-acid-type fruits. Detailed analysis of these specimens revealed the changes in their sugar and organic-acid contents during development. In doing so, this study provides data support for improving fruit quality, as well as elucidating the mechanisms by which sugars and organic acids are accumulated and metabolized. Overall, this work provides a scientific basis for the breeding of high-quality apricot varieties with high sugar and/or low acid contents.

1. Materials and Methods

1.1 Germplasm Resources

The apricot germplasm resources were introduced to the germplasm repository at the Shijiazhuang Fruit Research Institute (SFRI-HAAFS; Shijiazhuang, Hebei Province, China, 38° 7' N, 114° 32' E) at different times. The rootstock used was *Armeniaca sibirica*, and the planting density was 3 m × 4 m, with trees planted in north-south rows. Based on previous investigations of growth habits and fruit taste in combination with comprehensive evaluations of fruit appearance and flavor, 64 outstanding apricot germplasm resources were selected (Supplementary Table S1). Samples were collected during fruit ripening for the determination of sugar and organic-acid type and content. Additionally, six varieties, ‘Qingmisha’, ‘Hamazui’, ‘Zhenzhuyou’, ‘Jinhui’, ‘Shunpingganzhi’, and ‘Meishuo’, were selected from the resources as experimental materials. Samples were collected every week from 20 days after flowering until fruit ripening. Fifteen apricot fruits were randomly picked from the outer perimeter of each tree, then divided into three replicates with five fruits per replicate. All the apricot trees have the same management level.

Supplementary Table 1 The information of the apricot resource

No.	Cultivar	Origin	No.	Cultivar	Origin
1	Dapengwang	American	33	Shishengwanxing	Hebei, China
2	Jinshou	American	34	Shunpingganzhi	Hebei, China
3	Katy	American	35	Xiangbai	Hebei, China
4	Sungold	American	36	Yinxiangbai	Hebei, China
5	Hamaxing	Anhui, China	37	Yutianxiangbai	Hebei, China
6	Armenia apricot	Armenia	38	Yuzhouhong	Hebei, China
7	Jingcuihong	Beijing, China	39	Zihe	Hebei, China
8	Jingxianghong	Beijing, China	40	Jinhe	Hebei, China

9	Luotuohuang	Beijing, China	41	Wanxing	Hebei/ Liaoning, China
10	Maohong	Beijing, China	42	Jinxiang	Henan, China
11	Shanhuang	Beijing, China	43	Meishuo	Henan, China
12	Yubada	Beijing, China	44	Zaojinyan	Henan, China
13	Lanzhoudajiexing	Gansu, China	45	Guofeng	Liaoning, China
14	Zhanggongyuan	Gansu, China	46	Guoqiang	Liaoning, China
15	Kaili	Guizhou, China	47	Guozhixian	Liaoning, China
16	13-20	Hebei, China	48	Shajinhong No.1	Liaoning, China
17	95-26	Hebei, China	49	Xiaohongpao	Liaoning, China
18	9-D1	Hebei, China	50	Fengyuanhong	Shaanxi , China
19	Chuanzhihong	Hebei, China	51	Huaxianjiexing	Shaanxi, China
20	Erhong	Hebei, China	52	Lintongyinhuang	Shaanxi, China
21	Erhongyou	Hebei, China	53	Qinxing No.1	Shaanxi, China
22	Ganyu	Hebei, China	54	Golden Katy	Shandong, China
23	Jiguang	Hebei, China	55	Xinshiji	Shandong, China
24	Jinhui	Hebei, China	56	Hongjinzhen	Shandong, China
25	Jizaohong	Hebei, China	57	Hongxiangmi	Shandong, China
26	Julu No.1	Hebei, China	58	Zhenzhuyou	Shandong, China
27	Julu No.2	Hebei, China	59	Mingxing	Xinjiang, China
28	Julu No.3	Hebei, China	60	Saimaiti	Xinjiang, China
29	Julubaixing	Hebei, China	61	Yageleke	Xinjiang, China
30	Mingxing No.2	Hebei, China	62	Daguoxing	--
31	Perfect strain	Hebei, China	63	Dailing	--
32	Qingmisha	Hebei, China	64	Duanzhi	--
Note:--indicate the origin is unknown.					

2.2 Determination of Sugars and Organic Acids

identification and characterization of sugars and organic acids (sucrose, glucose, fructose, sorbitol, malic acid, citric acid, and quininic acid) were conducted using HPLC techniques as previously described (Jing et al. 2016). Analysis of sugars was performed using a system comprising a Waters 2695 pump, a Multospher® Sugar 5u column (250 mm × 4.6 mm × 5 µm; Waters, USA), and a 2414 refractive index (RI) detector. The organic acids were determined using a system that comprised a RIGOL L-3000 pump, an HP-C18-AQ column (250 mm × 4.6 mm, 5 µm), and a photodiode array detector. The mobile phase consisted of 0.1 M phosphoric acid buffer (pH 3.1) with a flow rate of 1.0 mL/min at 30 °C, and detection was carried out at 210 nm [4].

1.2 Statistical Data Analysis

Data processing and graph plotting were performed using Microsoft Excel 2007. Correlation analysis was conducted with IBM SPSS Statistics 19 (SPSS Inc., Armonk, NY, USA), and least-significant-difference analysis was used to establish the significance of differences between samples.

Histograms and box plots were created using Minitab 16. Clustered heatmaps were generated using HemI 1.0. Hierarchical clustering and heat-map analysis of apricot cultivars and parameters were performed using squared Euclidean distance and average linkage clustering algorithms [13].

2. Results

3.1 Distribution Characteristics of Sugars and Organic Acids in Fruits from Germplasm Resources Populations

Fructose, glucose and sucrose are the main sugars, accounting for more than 90% of the total sugars in apricot fruits. The mean fructose content is 12.71±6.28 mg·g^{-1} FW . The fructose contents range from 2.94 to 29.7 mg·g^{-1} FW, being mainly distributed in the range 1.5–22.5 mg·g^{-1} FW (89.1% of the population). Glucose content of the nature apricot fruits population averaged 29.2±15.59 mg·g^{-1} FW with a minimum of 3.59 mg·g^{-1} FW up to a maximum of 70.43 mg·g^{-1} FW. The glucose contents are mainly distributed at 12.0–60.0 mg·g^{-1} FW, accounting for 89.1% of the total sugar. Sucrose, as the main sugar component in apricot fruit, average 33.28±13.95 mg·g^{-1} FW. The sucrose contents range between 10.72 and 73.73 mg·g^{-1} FW, with 89.1% of the population distributed in the 22.0–67.5 mg·g^{-1} FW range.

Table 1 Classes and contents of sugars and organic acids in apricot resource fruits

	N	mean values (mg·g^{-1} FW)	standard deviation	coefficient of variation	minimum	maximum	skewness
Fructose	64	12.71	6.28	49.40	2.94	29.70	0.30
Glucose	64	29.20	15.59	53.39	3.59	70.43	0.70
Sucrose	64	41.19	13.95	33.87	10.72	73.73	0.43
Total sugar	64	82.70	22.60	27.33	38.48	138.78	0.30
Quininic acid	64	0.83	0.63	76.13	--	4.83	4.28
Malic acid	64	6.14	3.05	49.60	1.60	13.60	0.49
Citric acid	64	5.62	4.99	88.66	0.50	16.84	0.64
Total acid	64	12.60	3.87	30.72	4.091	20.93	0.24

Note: Two-years measurements for 64 resources were averaged.

The total sugar contents fall in the range 38.48–138.78 mg·g^{-1} FW, with a mean content of 58.65±22.6 mg·g^{-1} FW. The total sugar contents are mainly distributed at 54.5–115.5 mg·g^{-1} FW, accounting for 81.3% of the total (Figure 1 A and B, Table 1).

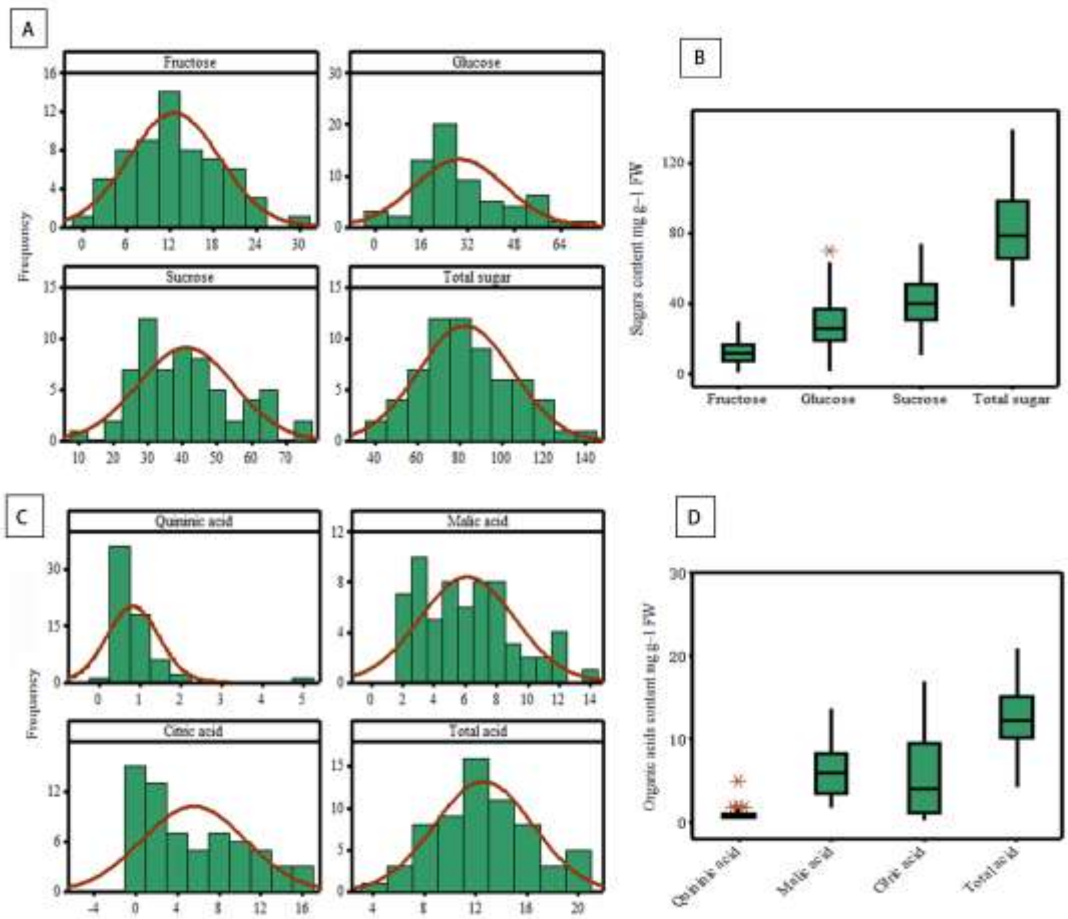


Figure 1 Distribution of sugars and organic-acids in the ripening fruits of the germplasm resources population

Apricot fruits contain much less quininic acid than malic and citric acids, making it the least abundant organic acid, with its lowest content difficult to detect and highest reaching 4.83 mg·g^{-1} FW; the average content is 0.83±0.63 mg·g^{-1} FW, mainly concentrated in the range 0.3–1.8 mg·g^{-1} FW (93.8%). The malic-acid contents for this population average 6.14±3.05 mg·g^{-1} FW with a distribution range of 1.6–13.6 mg·g^{-1} FW, where the content is mainly concentrated in the 1.6–8.5 mg·g^{-1} FW range (81.3% of the total population). For citric acid, the mean content in this population is 5.62±4.99 mg·g^{-1} FW, and the content distribution ranges from 0.5 to 16.8 mg·g^{-1} FW. The main concentrated distribution area is 0.5–12.5 mg·g^{-1} FW, which accounts for 90.6% of the population.

The total organic-acid contents in the apricot fruit of this population are 4.09–20.93 mg·g^{-1} FW and the mean value is 12.6±3.87 mg·g^{-1} FW. The contents are mainly concentrated in the 7.1–17.5 mg·g^{-1} FW interval, accounting for 81.3%. (Figure1 C and D, Table 1)

3.2 Distribution of Sugars and Organic Acids in the Fruits of Apricot Germplasm Resources

In the germplasm fruit, the absolute contents of fructose are the lowest , ranging from 2.17% to 35.48% and having relatively little influence on the total-sugar content. The content distributions for glucose and sucrose show certain differences: the absolute content of glucose directly affects the total-sugar content of apricot fruit, and its relative content is distributed between 3.66% and 59.82%. In contrast, the absolute content of sucrose is relatively evenly distributed, with its relative contents ranging from 18.97% to 96.20%, making it the main sugar component for germplasm resources (Figure 2 A and B).

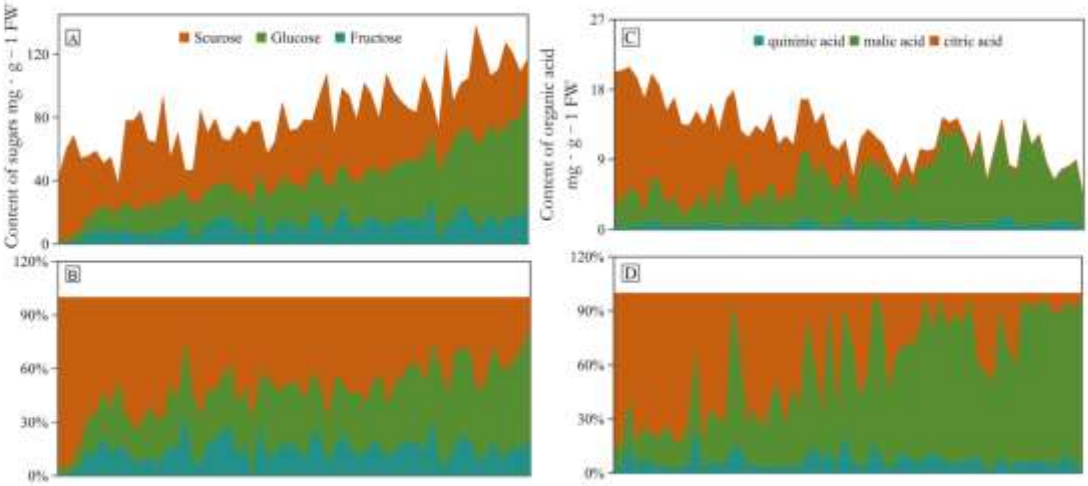
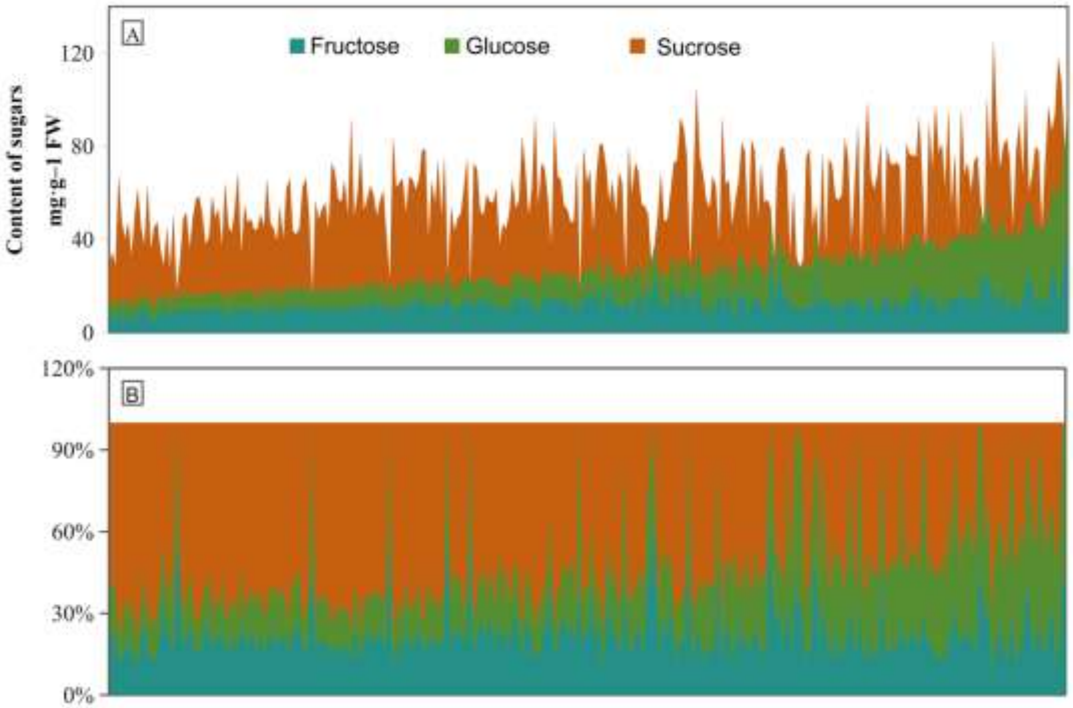
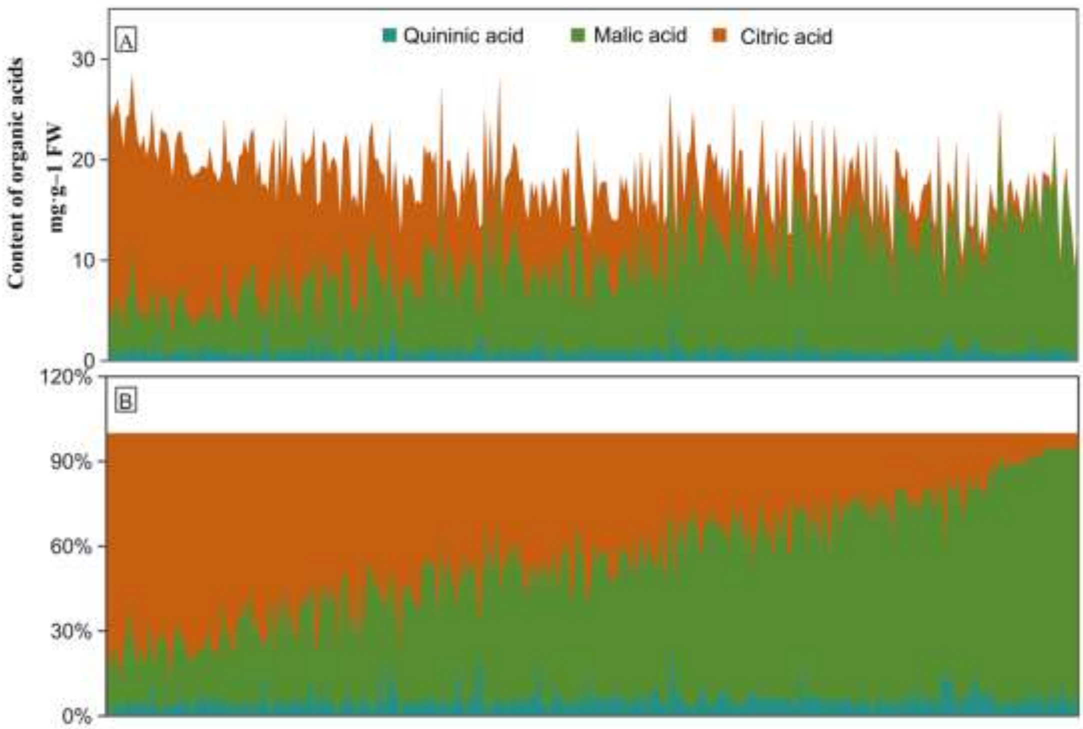


Figure 2 Distribution trends for sugars and organic acids in apricot germplasm fruits

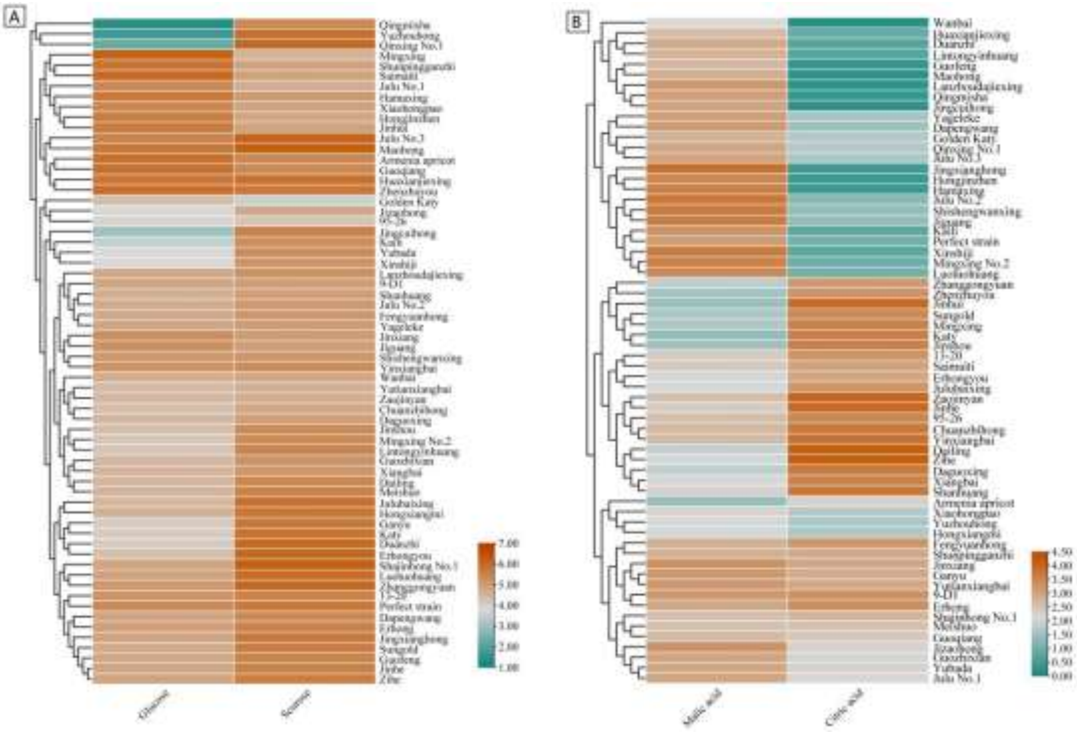
The germplasm fruits have the lowest quinine-acid contents and the smallest proportions, ranging from 1.60% to 24.58%. However, the distributions of malic and citric acids are different, with their relative contents ranging between 10.22%–94.37% and 1.91%–86.28%, respectively. Notably, in some apricot resources, the proportions of malic and citric acids are quite different. Whether from the perspective of absolute organic-acid content or relative content, there are some apricot resources with high proportions of malic acid and some with high proportions of citric acids. Therefore, we initially divided these resources into malic-acid-dominant type (mal-type) and citric-acid-dominant type (cit-type) (Figure 2 C and D). Additionally, similar sugar and organic acid distribution trends were observed in fruits of the natural apricot group (Supplementary Figure 1 and Supplementary Figure 2).



Supplementry Figure 1 Distribution trends for sugars content in nature apricot group fruits.



Supplementry Figure 2 Distribution trends for organic acids in nature apricot group fruits



Supplementry Figure 3 Cluster-analysis results for (A) sugars and (B) organic acids in apricot resource fruits.

3.3 Classification of Fruit Sugars and Organic Acids in Apricot Germplasm Resources

We identified 53 apricot resources with a ratio of glucose and sucrose (G/S) in base 2 log transformation, i.e., $|\log_2 (G/S)|$, lower than 1.5. When G/S is between 0.3 and 3, the fruit glucose and sucrose contents are between 25% and 75%, so we classify such fruit as two-sugar-accumulating type (two-sugar type). Only 'Mingxing No.1' is classified as glucose-dominant type (glu-type), with its value of $\log_2$ (G/S) being 1.66. There are 10 sucrose-dominant type (suc-type) resource varieties, especially 'Qingmisha' (G/S = 1:25.7), 'Yuzhouhong' (G/S = 1:25.3), 'Qinxing' (G/S = 1:16.5), and 'Jingcuihong' (G/S = 1:6.4). Their values of $\log_2$ (G/S) are lower than −2, meaning that the sucrose contents of these fruits are more than six-times their glucose contents, so they are classified as extreme sucrose resources (Figure 3A, Supplementary Table S2).

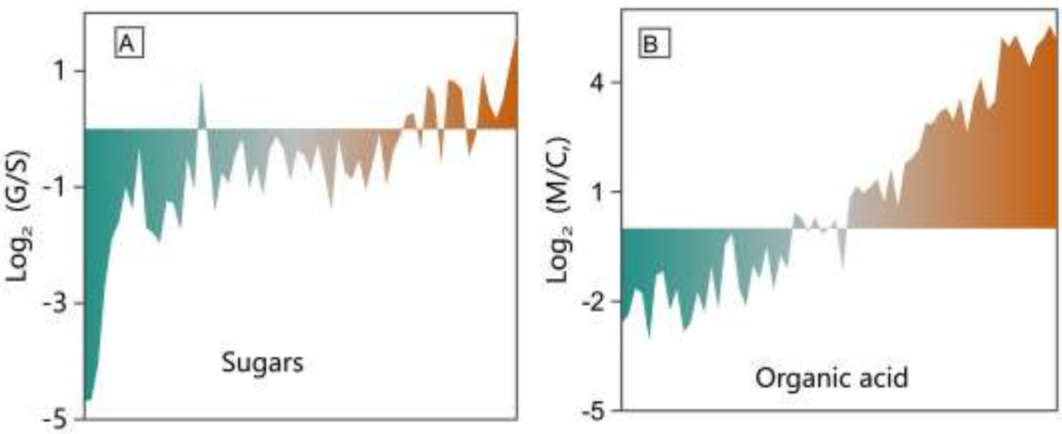


Figure 3 G/S and M/C ratio distributions for apricot resource fruits (M/C, the ratio of malic acid and citric acid; G/S, the ratio of glucose and sucrose).

Upon further analysis of the malic acid to citric acid (M/C) ratios in apricot fruits, we found that when $|\log_2 (M/C)| \leq 1$, the ratio of malic acid to citric acid is between 0.5 and 2, so they are classified as two-acid-accumulating type (two-acid type) resources. A total of 16 resources were classified as such, including 'Meishuo', 'Shunpingganzhi', 'Shajinhong No1', and 9-D1, whose values of log_2 (M/C) are all close to zero, indicating that the contents of malic acid and organic acid in the fruits of these varieties are equivalent (Supplementary Table S2).

Supplementary Table 2 The values of glucose/sucrose, malic acid/citric acid, and total sugars/total acids

	Cultivars	Glucose/ Sucrose	Malic/ Citric	Sugars/ Acids		Cultivars	Glucose/ Sucrose	Malic/ Citric	Sugars/ Acids
1	Dapengwang	1:1	4:1	8:1	33	Shishengwanxing	1:1	7:1	6:1
2	Jinshou	1:2	1:6	5:1	34	Shunpingganzhi	2:1	1:1	8:1
3	Katy	1:3	1:7	6:1	35	Xiangbai	1:2	1:3	5:1
4	Sungold	1:2	1:5	7:1	36	Yinxiangbai	1:1	1:2	4:1
5	Hamaxing	2:1	40:1	8:1	37	Yutianxiangbai	1:1	1:1	3:1
6	Armenia apricot	1:1	1:2	16:1	38	Yuzhouhong	1:25	2:1	9:1
7	Jingcuihong	1:6	37:1	7:1	39	Zihe	1:2	1:5	5:1
8	Jingxianghong	1:2	38:1	7:1	40	Jinhe	1:2	1:3	5:1
9	Luotuohuang	1:2	10:1	8:1	41	Wanbai	1:1	343:1	14:1
10	Maohong	1:1	32:1	18:1	42	Jinxiang	1:1	1:1	5:1
11	Shanhuang	1:1	1:3	5:1	43	Meishuo	1:2	1:1	7:1
12	Yubada	1:3	2:1	5:1	44	Zaojinyan	1:1	1:3	3:1
13	Lanzhoudajiexing	1:1	48:1	8:1	45	Guofeng	1:2	21:1	12:1
14	Zhanggongyuan	1:2	1:3	10:1	46	Guoqiang	1:1	1:1	10:1
15	Kaili	1:4	12:1	5:1	47	Guozhixian	1:2	2:1	6:1
16	13-20	1:1	1:2	7:1	48	Shajinhong No.1	1:3	1:1	10:1
17	95-26	1:1	1:2	2:1	49	Xiaohongpao	1:1	2:1	11:1
18	9-D1	1:1	1:1	4:1	50	Fengyuanhong	1:1	1:1	5:1
19	Chuanzhihong	1:1	1:2	3:1	51	Huaxianjiexing	1:1	6:1	19:1
20	Erhong	1:2	1:1	6:1	52	Lintongyinhuang	1:2	10:1	6:1
21	Erhongyou	1:3	1:2	9:1	53	Qinxing No.1	1:17	3:1	7:1
22	Ganyu	1:3	1:1	5:1	54	Golden Katy	2:1	3:1	5:1
23	Jiguang	1:1	7:1	6:1	55	Xinshiji	1:3	17:1	4:1
24	Jinhui	2:1	1:8	6:1	56	Hongjinzhen	2:1	32:1	8:1
25	Jizaohong	1:2	2:1	4:1	57	Hongxiangmi	1:2	2:1	11:1
26	Julu No.1	2:1	2:1	8:1	58	Zhenzhuyo	1:1	1:4	11:1

						u			
27	Julu No.2	1:1	9:1	5:1	59	Mingxing	3:1	1:5	9:1
28	Julu No.3	1:2	3:1	12:1	60	Saimaiti	2:1	1:2	9:1
29	Julubaixing	1:3	1:3	7:1	61	Yageleke	1:1	4:1	8:1
30	Mingxing No.2	1:2	12:1	5:1	62	Daguoxing	1:1	1:5	4:1
31	Perfect strain	1:1	8:1	11:1	63	Dailing	1:2	1:6	4:1
32	Qingmisha	1:26	29:1	5:1	64	Duanzhi	1:4	11:1	11:1

There are 27 resources for which $\log_2$ (M/C) > 1, i.e., their M/C ratios are greater than 2, which we classify as a malic-acid-dominant type (mal-type) resource. Among these resources, there are 19 with $\log_2$ (M/C) > 2, especially 'Maohong' (M/C = 32:1), 'Jingcuihong' (M/C = 36.8:1), 'Jingxianghong' (M/C = 38.2:1), 'Hamazui' (M/C = 39.7:1), 'Lanzhoudajie' (M/C = 47.8:1), and 'Wanbai' (M/C = 342.5:1), that have $\log_2$ (M/C) values greater than 5.

There are 21 resources with $\log_2$ (M/C) values < 1, that is, their M/C ratios are less than 0.5, which we classify as a citric-acid-dominant type (cit-type). The fruits with $\log_2$ (M/C) < −2 include 'Jinhui' (M/C = 1:8.4), 'Kate' (M/C = 1:7.1), 'Dailing' (M/C = 1:6.1), 'Jinshou' (M/C = 1:6), 'Zihe' (M/C = 1:5.2), 'Mingxing' (M/C = 1:5), 'Daguo' (M/C = 1:4.7), 'Sungold' (M/C = 1:4.7) and 'Zhenzhuyou' (M/C = 1:4.4) (Figure 3B, Supplementary Table S2).

3.4 Development Trends for Sugar and Organic Acids in Apricot Fruits

Since no extreme glu-type germplasm was identified in the apricot fruit resources, we screened the two-sugar-type and suc-type resources, thoroughly exploring the variability in sugar levels during fruit development. Both fructose and sucrose contents are maintained at relatively low levels during the early development and expansion stages. However, the two sugar levels increase differently when the fruit reaches maturity, about 7–14 days before the fruit is fully ripe. Among them, in the two-sugar-type apricot varieties 'Shunpingganzhi' and 'Hamazui', the increases in fructose and sucrose contents are similar, both 6–9-fold. In contrast, the fructose contents of 'Qingmisha' and 'Lanzhoudajie' increase 2–4-fold during the ripening stage, but their sucrose content increases ~10-fold (Figure 4).

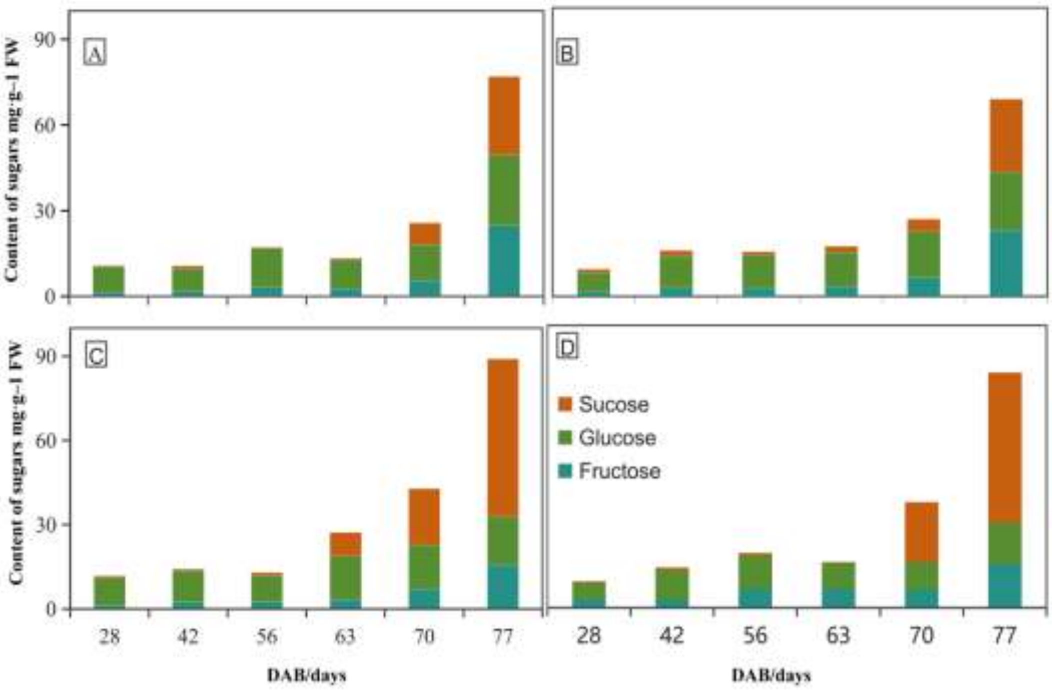


Figure 4 Development trends for sugar contents in apricot fruits.

In the course of development, the quininic-acid contents change little, but then changes significantly with the maturity of the fruit. At the same time, malic-acid content always maintains a high level during the fruit growth and development process. However, as the fruit enters the ripening stage (7–14 days before maturity), the malic-acid content all show significant downward trends. The malic-acid content is decreased to 30%–50% that of the developmental stage in the ripening stage and to 20% or even lower in the cit-type resources (Figure 5).

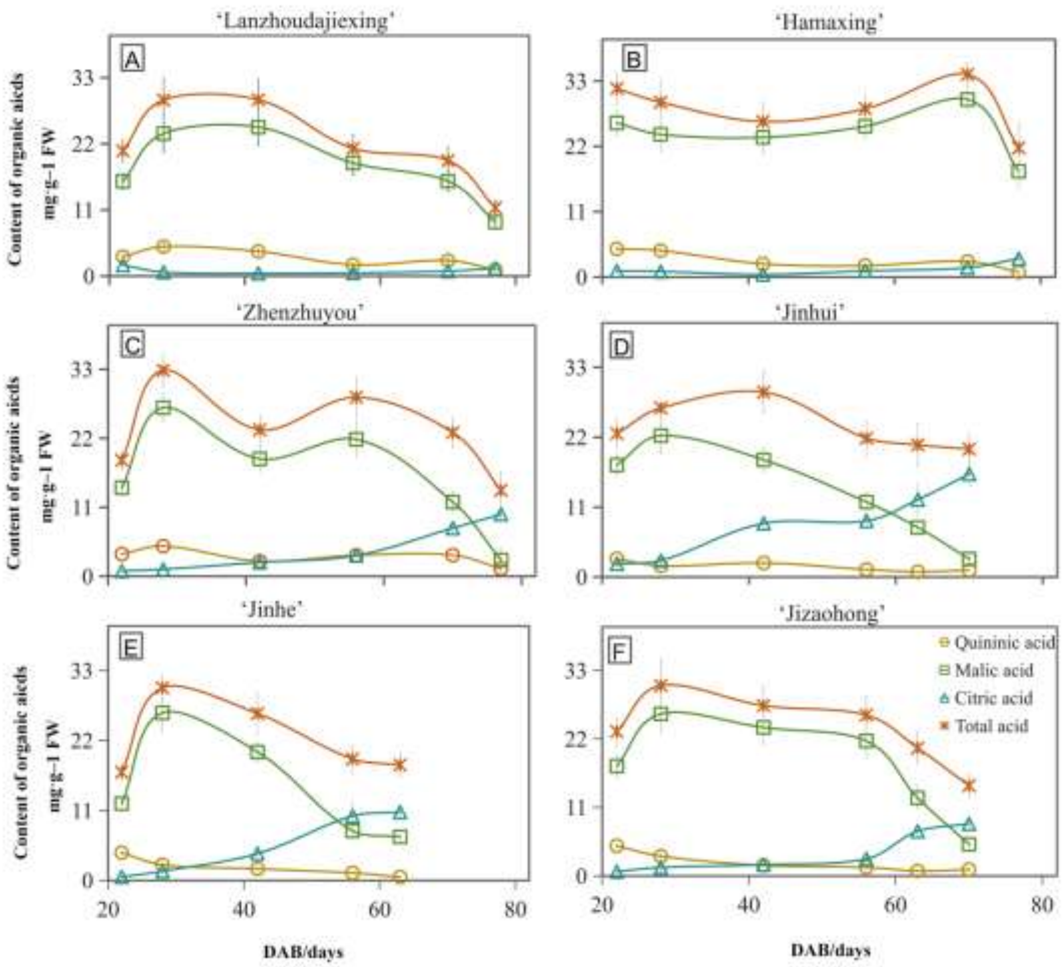


Figure 5 Development trends for acid contents in apricot fruit

3. Discussion

The sugars in apricot fruits mainly include fructose, glucose, and sucrose, so different varieties can be divided into reducing-sugar-type, suc-type, and two-sugar-type fruits based on their characteristics [14]. In this study, a systematic analysis of the sugar compositions of natural populations and fresh apricot fruits showed that the fructose content is lower compared with the other two sugars, and there are differences between varieties, which is consistent with previous reports [15]. In cultivated apricot fruits, the glucose and sucrose contents and their ratios show remarkable diversity among different varieties. By setting $|\log_2(G/S)| < 1.5$ as a criterion, this study divides fruit into sucrose, glucose (reducing-sugar type), and two-sugar types. It is important to note that existing research focuses on different sugar contents in apricot fruit, and with the formula in this study, can also introduce similar sugar classification, for example, Caliskan et al. classified 15 apricot resource varieties into two sucrose, one glu-type (reducing sugar), and 12 two-sugar types (Supplementary Table S3) [16]. In fact, this difference in sugar composition is very common in apricot fruits, and many studies have highlighted this point, but few studies have fully explored this phenomenon.

Supplementary Table 3 Sugar content and proportion of the fruits in some foreign apricot resources (Caliskan *et al*, 2012)

	Fructose ($g100\ g^{-1}$ of FW)	Glucose ($g100\ g^{-1}$ of FW)	Sucrose ($g100\ g^{-1}$ of FW)	Total Sugar	G/S	Log_2 (G/S)	Type
Şahinbey	0.9	1.4	5.6	7.8	1:4	–2.0	Suc-type
Ninfa	0.9	1.9	5.8	8.7	1:3.1	–1.61	Suc-type
Septik	1.3	1.9	5.3	8.6	1:2.8	–1.48	Two-sugars-type
Precoce de Tyrinthe	0.6	2.1	5.2	7.9	1:2.5	–1.31	Two-sugars-type
Çağataybey	2.8	3.1	7.5	13.4	1:2.4	–1.27	Two-sugars-type
Harcot	1.2	2.8	5.8	9.8	1:2.1	–1.05	Two-sugars-type
Aurora	0.8	2.7	5.5	8.9	1:2	–1.03	Two-sugars-type
Bebeco	0.7	3	5.9	9.7	1:2	–0.98	Two-sugars-type
Mean	1.2	2.7	5.2	9.1	1:1.9	–0.95	Two-sugars-type
Antonio Errani	1.3	2.6	4.9	8.8	1:1.9	–0.91	Two-sugars-type
Roxana	1.6	2.6	4.9	9	1:1.9	–0.91	Two-sugars-type
Super Gold	1.6	3.5	5.8	10.4	1:1.7	–0.73	Two-sugars-type
Çağrıbey	0.9	2.9	4.6	8.4	1:1.6	–0.67	Two-sugars-type
Alata Yıldızı	1.5	3.5	4.9	10	1:1.4	–0.49	Two-sugars-type
Dr Kaşka	1.9	3.8	1.2	6.9	3.2:1	1.67	Glu-type

From the perspective of fruit development, the proportional distribution of sugar has stage characteristics. In the ripening stage, the type of sugar changes, while in the young and expansion stages, reducing sugars such as fructose and glucose are dominant, acting as the main energy materials for the development of reduced sugar crops [17]. When the apricot fruit enters maturity, organic matter accumulates mainly as sucrose, leading to a change in the sugar type of the fruit. The results of our correlation analysis indicate that fructose, glucose, and sucrose are negatively correlated, that is, the reduced-sugar content decreases and is converted into sucrose, which gradually accumulates in the fruit. This trend is also seen in fruits such as apples, citrus, and peaches [4, 6, 18, 19].

In this study, an extremely high proportion of citric acid varieties were present in apricot fruits. Therefore, we classified the fruit acid type according to the $\log_2$ (M/C) criteria presented above. Previous studies have pointed out that the organic acids in apricot fruits can be classified as malic acid and citric acid, but only two varieties, New (malic acid) and Kate (citric acid), have been studied, providing results that are consistent with those of this study [20]. In addition, when the apricot varieties reported in the literature were classified, we found that the $\log_2$ (M/C) values of 'Dajiexing', 'Kaili' and 'Luotuohuang' were 4.00, 7.45, and 6.60, respectively, belonging to the mal-type, which are consistent with the classification results in this study [8, 11]. Similarly, $\log_2$ (M/C) values of −2.43 and −2.06 have been reported for Kate, classifying it as cit-type, which is consistent with our study results ($\log_2$ (M/C) = −2.83) [8, 21].

This study classified apricot resources into mal-type, cit-type, and two-acid type, and found that malic acid accounted for more than 90% of the total acid in the fruit development stage, while the other acids were less abundant, accounting for less than 10%. This rule is consistent with the organic acid changes in developing fruits such as apple and jujube, which are dominated by malic acid [22, 23]. The richness of apricot fruit acid types is mainly reflected in the fruit ripening period. Although the total-acid content decreases, which is mainly due to the lower malic-acid content, the citric-acid content increases in some varieties.

4. Conclusions

Through a deep analysis of the compositions of sugars and organic acids in apricot fruit, we have provided a solid theoretical basis for the improvement of apricot cultivation. In addition, our classification method based on sugar and organic acid characteristics not only facilitates the standardization of resources from various countries, it also promotes the effective utilization and development of apricot germplasm resources. In conclusion, this study provides important scientific data and practical guidance for the improvement of apricot fruit quality and breeding practice.

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Data availability Data are available upon request to the corresponded author.

Declarations

Compliance with ethical standard

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical Standards: This article does not contain any studies with human participants or animals performed by any of the authors.

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