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Comparison of physical and chemical composition of three chinese jujube (*Ziziphus jujuba* Mill.) cultivars cultivated in four districts of Xinjiang region in China

Kai CHEN[1], Dingyu FAN[2], Bing FU[1], Jianzhong ZHOU[1], Huanrong LI[1*]

Abstract

This study investigated the physical and chemical composition of three jujube fruits cultivated in China. The objective was to explore the effect of jujube genotype and cultivation districts on the quality of jujube fruits. Results showed significant differences on their physical and chemical composition. The Junzao cultivar contained relatively low level on the total dietary fiber, protein, total sugar, and total titratable acids. The Huizao cultivar possessed the mediate level of the sugar-to-acid ratio and ascorbic acid. The Dazao cultivar showed high level of the total dietary fiber, protein, sugar, and total acids. The cultivation districts exerted important roles in altering the physicochemical indexes of the same jujube cultivar. The Junzao cultivar harvested in the Hami and Kashi districts showed the significant difference on the level of the sugar-to-acid ratio and ascorbic acid compared with that in the Akesu and Hetian districts. The Huizao cultivar in the Kashi area possessed higher content of the total soluble dietary fiber than that in the Akesu and Hetain districts. Principal component analysis indicated that the parameters that differentiated these jujube cultivars appeared to be the total dietary fiber, protein, total sugar, fructose, glucose, sucrose, and total titratable acids.

Keywords: jujube fruits; composition; cultivation district; principal component analysis.

Practical Application: This study could benefit the quality development of jujube fruits in the Xinjiang region of China.

1 Introduction

Jujube (*Zizyphus jujuba* Mill.) belongs to the Rhamnaceae family (Chen et al., 2015a). It has gained much attention in the field of food and nutritional sciences due to its nutritional and medicinal properties (Wang et al., 2016a). Jujube fruits are mainly consumed freshly, and can also be processed into the jujube products, such as compotes, alcoholic beverage, jam, candied snack, sweetened tea syrup, cake, and bread (Zozio et al., 2014; Wojdyło et al., 2016a).

Jujube fruits possess an attractive red appearance and a sweet taste (Choi et al., 2016). Glucose, fructose, and sucrose are the main nutrients in jujube fruits that contribute the sweetness to jujube fruits (Wang et al., 2016b; Zhao et al., 2008a; Li et al., 2007). Besides, jujube fruits also contain high level of organic acids, minerals, protein, vitamins, and polyphenols (Park et al., 2012; Gao & Wang, 2013). These components play important roles in affecting the nutritional properties of jujube fruits. For example, phenolic compounds in jujube fruits possess antioxidative, anti-cancer, anti-obesity, and anti-diabetes properties (Wojdyło et al., 2016b; Yu et al., 2012; Plastina et al., 2012). It has been accepted that genotype is the primary factor that determines the physical and chemical attributes of fruits, whereas geographic environment and cultivation management affect the biosynthesis and metabolisms of nutrients in fruits (Guo et al., 2016; Gündüz & Saraçoğlu, 2014). Guo et al. has reported the physical and chemical properties of jujube fruits (Guo et al., 2015b). However, the effect of different geographic regions on the physical and chemical composition of Chinese jujube cultivars remained uncovered to our best knowledge.

China is the largest jujube production country that produces more than 85% of the total jujube yield in the world (Wang et al., 2016a). Besides, China is the only country that exports jujube fruits (Liu & Zhao, 2008). Xinjiang is an important jujube production region in China and its annual yield has significantly increased since 2010 (Jin et al., 2015). It has been reported that the Xinjiang region has a total 483,628 hectares jujube planting area, which can result in a more than 2.5 million tons annual production on the fresh jujube fruits (Chen et al., 2017). Geographically, Xinjiang is in the northwest of China, and it possesses a high day-to-night temperature difference. Meanwhile, the Xinjiang region has a long sunshine duration and high sunshine intensity with dry air and a low annual precipitation (Xie et al., 2009). It has been reported that the different districts in the Xinjiang regions show the great differences on the temperature, sunshine intensity, frost-free period, and rainfall amounts (Cui et al., 2013). Such environmental differences could alter the accumulation of nutrients in jujube fruits, resulting in the quality alteration in jujube fruits in the Xinjiang region. Therefore, it is necessary to investigate the effect of the different districts in the Xinjiang region on the physical and chemical properties in jujube fruits. This could provide useful information on the quality control and development of jujube fruits in the Xinjiang region of China. To this end, we chose four major jujube production districts in the Xinjiang region, and two jujube cultivars in each district

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[1] *School of Food Science and Pharmacy, Xinjiang Agriculture University, Urumqi, Xinjiang Uygur Autonomous Region, China*
[2] *Institute of Horticulture Corp, Xinjiang Academy of Agricultural Sciences, Urumqi, Xinjiang Uygur Autonomous Region, China*
*Corresponding author: chenk117@sohu.com

were selected. The detailed physical and chemical composition of these jujube samples were measured and compared. Moreover, the multivariate analysis, using these parameters as variables, was carried out to investigate the quality similarity of these cultivars cultivated in these districts.

2 Materials and methods

2.1 Jujube fruit samples

Four districts in the Xinjiang Uygur Autonomous Region of China were selected in the present study, including the district of Hami, Akesu, Kashi, and Hetian. One jujube fruit cultivar, *Zizyphus jujuba* cv. Dazao, was harvested in the Hami district. The *Zizyphus jujuba cv*. Junzao cultivar was cultivated in these four districts, whereas the *Zizyphus jujuba* cv. Huizao cultivar was harvested in the Akesu, Kashi, and Hetian districts. All the jujube samples were harvested at their maturation stage on Oct. 2nd, 2014. In each cultivar, about 5 kg jujube fruits were randomly picked from each jujube plant, and 10 jujube plants were randomly selected for harvest. After the harvest, the jujube fruits were placed in plastic bags under a cooler and immediately transported to our laboratory for analysis.

2.2 Determination of fresh mass of fruits

Average fresh mass of the jujube fruits was determined according to a published method (Bastos et al., 2016). Briefly, a total of 30 fresh jujube fruits in each cultivar were randomly selected, and the total weight of the fruits was measured using an ME303 balance (METTLER TOLEDO International Trade Co. Ltd, Shanghai, China). The average fresh mass of the fruits was calculated by the total weight of fruits divided by the fruit number. Each measurement was carried out in triplicate.

2.3 Determination of shape ratio of fruits

Shape ratio of the jujube fruit refers to a ratio of polar diameter to equatorial diameter of fruit (Bastos et al., 2016). In the present study, 30 jujube fruits in each cultivar were randomly picked. The equatorial diameter of each fruit was determined by measuring the horizontal distance of the jujube fruit, whereas the vertical distance of fruit was used to determine the polar diameter of the fruit. The shape index of each cultivar was determined by averaging the shape index of these 30 jujube fruits. Each measurement was performed in triplicate.

2.4 Determination of moisture content, ash, and fiber in fruits

The analysis of moisture content of the jujube fruits followed a standard method (Association of Official Analytical Chemists, 2010). Briefly, the jujube fruits after removing the seed were homogenized using an HR2864 Philip blender (Philips Investment Co. Ltd., Shanghai, China), and then the resultant homogenate was kept in a drying oven at 70 °C under a 13.3 KPa vacuum pressure. After the fruit weight was not altered in the oven, the weight difference of the homogenate before and after the drying process was used to determine the moisture content. Moisture content analysis was carried out in triplicate. Ash content in the jujube fruits was measured according to an AOAC method (Association of Official Analytical Chemists, 2010). In brief, the jujube fruits homogenate after removing the seed (2.00 g) was placed in a crucible. Afterwards, the fruit sample was heated at 550 °C to ash, and the ash content was weighed. Ash content measurement was performed in triplicate. The total dietary fiber, insoluble dietary fiber, and soluble dietary fiber content of the jujube fruits were measured according to a published method (Li et al., 2007). Each analysis was carried out in triplicate.

2.5 Determination of total sugar content and individual sugar content in fruits

Six fruits in each jujube cultivar were randomly selected. After the seed was removed, the resultant fruits were immediately homogenized using an HR2864 Philip blender (Philips Investment Co. Ltd., Shanghai, China). Afterwards, the homogenate (25 g) was transferred into a beaker and mixed with 150 mL distilled water. The resultant mixture was heated at 80 °C in a water bath for 30 min, and then filtered into a 250-mL volumetric flask. Subsequently, 3 mL of the mixture containing 1 M zinc acetate and 0.25 M potassium ferrocyanide was added to the volumetric flask, and then the flask was brought up to the volume using distilled water. Finally, 10 mL of the resultant mixture was titrated using Fehling's method to measure the total soluble sugar content (Association of Official Analytical Chemists, 2010). Glucose was used as the external standard, and the total sugar content was expressed as gram glucose equivalents per 100 g of fresh fruit weight (g/100 g FW).

The analysis of individual sugar content in the jujube fruits, including glucose, fructose, and sucrose followed a published method (Park & Kim, 2016; Wang et al., 2012). After homogenizing the fruits without seeds, the homogenate (20 g) was extracted using 100 mL water in an ultrasonic bath (40 kHz) for 60 min at 4 °C. Afterwards, the extract was centrifuged at 15,000 rpm for 10 min at 4 °C to collect supernatant. The supernatant was filtered through 0.45 µm membrane filters and then directly injected to a high-performance liquid chromatography (HPLC) with a 20 µL injection volume. A Shimadzu LC-20A HPLC system (Shimadzu, Kyoto, Japan), equipped with an Intertsil NH_2 column (4.6 mm × 250 mm, 5 µm, Shimadzu, Kyoto, Japan), was used to separate these sugars. The mobile phase consisted of 20: 80 (v/v) acetonitrile: water. An isocratic elution program was carried out using a flow rate at 0.5 mL/min. The column was maintained at 35 °C during the elution program. The external standards, glucose, sucrose and fructose, were used for the quantitation of the individual sugars in the jujube fruits (g/100 g FW).

2.6 Determination of protein content in fruits

The protein content of the jujube fruits was determined using the standard AOAC method (Association of Official Analytical Chemists, 2010). The analysis was performed in triplicate, and the protein content was calculated from the nitrogen content (%N × 6.25).

2.7 Determination of titratable acid in fruits

Six jujube fruits were randomly selected. The fruits (50 g) after the removal of seeds were homogenized and then centrifuged at 10,000 g for 20 min. Afterwards, the supernatant was collected and then titrated with 0.1 M NaOH solution to pH 8.2. Citric acid was used as the external standard, and the titratable acid in the fruit was expressed as mg citric acid equivalents per 100 gram of fruit fresh weight (mg Citric acid/ 100 g FW). Each measurement was carried out in triplicate.

2.8 Determination of ascorbic acid in fruits

The ascorbic acid content in the jujube fruits was measured according to a published method with minor modifications (Jiang et al., 2004). Six fruits after removing the seeds were homogenized. Afterwards, the homogenate (50 g) was mixed with 50 mL of 0.02 g/mL oxalic acid solution. The resultant mixture was centrifuged at 15,000 rpm for 15 min at 4 °C to collect supernatant. The supernatant (10 mL) was titrated with 0.1% 2,6-dichlorophenolindophenol to exhibit a permanent pink color. The ascorbic acid content in the fruit was expressed as mg 2,6-dichlorophenolindophenol equivalents per 100 g of fresh fruit weight (mg/100 g FW).

2.9 Determination of cyclic adenosine monophosphate (cAMP) in fruits

The analysis of the cyclic adenosine monophosphate (cAMP) content in the jujube fruits was based on the published methods (Chen et al., 2015b; Zhang et al., 2009). A diamonsil C18 column (4.6 mm × 250 mm, 5 μm, Shimadzu, Kyoto, Japan) was used to analyze the cAMP in the fruit sample on a Shimadzu LC-20A HPLC system. The mobile phase was comprised of 10:90 (v/v) methanol: 0.05 M monopotassium arsenate. An isocratic elution was used with a flow rate of 1.0 mL/min and the column was maintained at 35 °C during the elution program. The wavelength on SPD-20A detector was set at 256 nm. The external cAMP was used to quantify the cAMP content in the sample (μg/g FW).

2.10 Determination of total flavonoids in fruits

Total flavonoids content in the jujube fruits were determined using a published method with minor modifications (Wang et al., 2016a). Briefly, the fruits after removing the seed were homogenized and the resultant homogenate (50 g) was mixed with 150 mL of ethanol: water (60: 40, v/v). Afterwards, the mixture was sonicated for 10 min, and then brought to 250 mL using the same extraction solvent. Subsequently, 5.0 mL of the extract was mixed with 0.6 mL of 5% $NaNO_2$ solution in a 25-mL volumetric flask. The resultant mixture was vortexed and then kept in the darkness for 6 min. Afterwards, 1 mL of 10% $A1(NO_3)_3$ was added to the mixture. The mixture was kept in the darkness for 6 min, followed by mixing with 10 mL of 4% NaOH solution. Finally, the mixture was vortexed and then brought up to the calibration level using ethanol: water (60: 40, v/v). The final mixture was kept in the darkness for 15 min, and then the absorbance was recorded at 510 nm. The total flavonoids content was expressed as mg rutin equivalents per gram of fresh weight (mg/g FW). Each measurement was performed in triplicate.

2.11 Statistical analysis

Data were expressed as the mean ± standard deviation of triplicate tests. One-way analysis of variance (ANOVA) was used to evaluate the significant differences on the means under the least significance difference test at a significant level of 0.05. Principal component analysis was carried out to investigate the similarity of these jujube fruits using these detected parameters as variables (SPSS version 19.0, Chicago, IL, USA).

3 Results and discussion

3.1 Physicochemical and chemical properties

The Huizao cultivar harvested in the Akesu, Kashi, and Hetian districts exhibited the lowest fruit weight, ranging of 8.03 to 9.45 g (Table 1). This cultivar exhibited the similar fruit weight among these districts. The Junzao cultivar showed significantly higher fruit weight (16.23 to 21.62 g) than the Huizao cultivar. It should be aware that the Junzao cultivar cultivated in the Hetian and Kashi districts displayed the similar fruit weight, whereas a significant difference on the fruit weight of this cultivar was found in the district of Akesu and Hami. The Dazao cultivar was harvested only in the Hami district and its fruit weight was 16.95 g.

The fruit shape development has been confirmed to be essentially determined by fruit genotype (Cao et al., 2015; Kurian & Peter, 1997). Climate, soil type, and management strategy also play important roles in altering the shape of fruits. Normally, fruits cultivated under high temperature condition exhibit a long fruit shape, whereas low temperature condition could result in fruits with more round shape (Li et al., 2016). In the present study, the Dazao cultivar in the Hami district possessed a 1.04 fruit shape index, indicating that the shape of this cultivar was round. The other jujube fruit cultivars in this study had the shape index above 1.3, suggesting that these cultivars showed a long fruit shape. It should be aware that the Junzao cultivar harvested in the Kashi and Hetian districts showed a less fruit shape index than those in the Akesu and Hami districts. Similarly, a smaller fruit shape index was also found in the Huizao cultivar cultivated in the Hetian and Kashi districts than the Akesu district. These indicated that the difference on the climates of these districts might also affect the jujube fruit shape development. For instance, the Kashi district belongs to the classic arid continental climate and it has sufficient daylight and high temperature. Meanwhile, this district possesses less precipitation, rapid evaporation, and high day-to-night temperature difference. The Akesu district is located at an extreme arid desert climate with a total 2800-3000 hours annual daylight period and an average annual precipitation of 65.4 mm. The Hetian district belongs to a warm arid desert climate and its average annual temperature is around 14 °C. The Hami district, compared to the other three districts, possesses lower average annual temperature but higher daylight period.

Moisture content has been considered a critical parameter to evaluate the quality of jujube fruits, and it can be significantly affected by genotype and cultivation conditions (Maraghni et al., 2011). In the present study, the Dazao cultivar harvested from the Hami district had the moisture content of 68.52 g/100 g FW,

Table 1. Individual fruit weight, fruit shape index, moisture, fiber, protein, ash, total sugars, fructose, sucrose, glucose, total acids, sugar-acid ratio, ascorbic acid, cAMP, total flavonoid contents of two main cultivars of jujube in four districts. Each value is expressed as means ± standard deviation (n = 3). Means with different letters within a column are significantly different (p < 0.05) by Bonferroni t-test.

	Disctrict							
	Dazao	Junzao				Huizao		
	Hami	Hami	Akesu	Kashi	Hetian	Akesu	Kashi	Hetian
Fruit weight (g)	16.95 ± 0.61cd	21.62 ± 0.84a	16.24 ± 0.72d	17.92 ± 0.96bc	19.03 ± 1.66b	8.09 ± 0.56e	9.45 ± 0.32e	8.03 ± 0.69e
Fruit shape index	1.04 ± 0.03d	1.50 ± 0.02ab	1.52 ± 0.03a	1.43 ± 0.02b	1.30 ± 0.05c	1.50 ± 0.06ab	1.47 ± 0.05ab	1.43 ± 0.06b
Mc (g/100 g)	68.52 ± 0.28a	67.36 ± 0.01b	76.5 ± 0.07c	72.91 ± 0.04d	64.31 ± 0.02e	63.59 ± 0.06f	63.13 ± 0.01g	58.34 ± 0.01h
TDF (g/100 g)	7.32 ± 0.15a	5.00 ± 0.07e	5.45 ± 0.20d	4.85 ± 0.24e	4.95 ± 0.10e	5.64 ± 0.18cd	5.9 ± 0.04c	6.84 ± 0.18b
IDF (g/100 g)	6.36 ± 0.31a	5.11 ± 0.15bc	5.54 ± 0.33b	4.59 ± 0.33c	3.75 ± 0.36d	5.59 ± 0.33b	6.33 ± 0.49a	4.02 ± 0.06d
SDF (g/100 g)	0.11 ± 0.01d	0.17 ± 0.04bc	0.23 ± 0.01a	0.23 ± 0.01a	0.13 ± 0.00cd	0.12 ± 0.01cd	0.21 ± 0.07ab	0.10 ± 0.01d
Protein (g/100 g)	3.97 ± 0.09a	1.87 ± 0.04e	2.28 ± 0.22d	2.51 ± 0.09c	3.06 ± 0.09b	2.47 ± 0.14cd	2.36 ± 0.04cd	3.04 ± 0.06b
Ash (g/100 g)	1.05 ± 0.01b	1.10 ± 0.00a	1.01 ± 0.01c	0.86 ± 0.02d	0.78 ± 0.02e	1.03 ± 0.03bc	0.80 ± 0.01e	1.09 ± 0.01a
Total sugar (%)	30.23 ± 0.96bc	29.31 ± 0.79bcd	27.19 ± 1.05e	30.56 ± 0.43abc	28.68 ± 0.39d	31.7 ± 0.51a	29.15 ± 0.92cd	30.71 ± 0.84ab
Fructose(%)	6.95 ± 0.15b	4.40 ± 1.19d	4.52 ± 0.21d	7.15 ±0.00b	3.24 ± 0.19e	5.04 ± 0.04d	6.16 ± 0.14c	8.66 ± 0.06a
Glucose(%)	4.24 ± 0.27c	4.31 ± 0.03c	3.18 ± 0.32d	6.58 ± 0.76b	2.97 ± 0.90d	4.66 ± 0.72c	5.35 ± 0.80c	8.44 ± 0.52a
Sucrose(%)	17.96 ± 0.24c	18.49 ± 0.90c	17.73 ± 1.71cd	16.98 ± 0.04cd	25.53 ± 0.80a	21.94 ± 0.15b	16.39 ± 0.47d	25.8 ± 0.86a
Titratable acids(%)	3.12 ± 0.12a	2.17 ± 0.06bc	3.09 ± 0.11a	2.34 ± 0.53bc	2.76 ± 0.00ab	2.56 ± 0.76abc	1.98 ± 0.12c	3.01 ±0.06a
Sugar-to-acid ratio	9.7 ± 0.55d	13.5 ± 0.02abc	8.80 ± 0.50d	13.59 ± 3.37ab	10.38 ± 0.14bcd	13.09 ± 3.47abc	14.75 ± 1.05a	10.2 ± 0.35cd
AA (mg/100 g)	185.46 ± 2.95a	221.17 ± 0.73b	191.45 ± 1.90c	196.09 ± 1.25d	166.86 ± 0.42e	182.64 ± 0.11f	244.57 ± 1.94g	162.5 ± 1.43h
cAMP (μg/g)	37.65 ± 0.87e	53.07 ± 1.01c	87.5 ± 1.63a	50.48 ± 2.91c	67.66 ± 1.94b	42.74 ± 1.41d	20.35 ± 1.03f	37.08 ± 1.08e
Total flavonoids (mg/g)	41.21 ± 4.64c	48.9 ± 2.21b	58.36 ± 1.82a	62.72 ± 3.75a	58.77 ± 2.93a	46.12 ± 2.03bc	44.1 ± 1.28bc	43.62 ± 4.27bc

Mc = moisture content; TDF = total dietary fiber; IDF = insoluble dietary fiber; SDF = soluble dietary fiber; AA = ascorbic acid.

whereas the Junzao cultivar cultivated in these districts showed the moisture content ranging of 64.31 g/100 g FW to 76.50 g/100 g FW (Table 1). It was observed that the Huizao cultivar exhibited slightly low moisture content than the other two cultivars. Additionally, the same cultivar cultivated in different districts exhibited the difference on the moisture content. For instance, The Junzao cultivar showed higher moisture content in the Akesu and Kashi districts than that harvested in the Hami and Hetian districts. Similarly, higher moisture content was also found in the Akesu and Kashi cultivated Huizao cultivar in comparison with that harvested in the Hetian district.

The total fiber content in the jujube fruits consisted of the insoluble and the soluble dietary fiber content (Table 1). These Chinese jujube cultivars exhibited higher insoluble fiber content. Regarding the insoluble fiber content, the Dazao cultivar showed the highest value (6.36 g/100 g FW). The insoluble content in the Junzao cultivar from these districts ranged from 3.75 g/100 g FW to 5.54 g/100 g FW. The Huizao cultivar showed its insoluble fiber content of 4.02 g/100 g FW to 6.33 g/100 g FW. Meanwhile, cultivation districts also altered the insoluble fiber content in the same jujube cultivar. For example, the lowest insoluble fiber content in the Junzao cultivar was found in the Hetian district. The Hetian cultivated Huizao cultivar exhibited the lowest insoluble fiber content. These cultivars contained the soluble fiber content of 0.10 g/100 g FW to 0.23 g/100 g FW, which was lower than jujube fruits reported by a previous study (Li et al., 2007). The soluble fiber content in the Dazao cultivar harvested at the Hami district was 0.11 g/100 g FW. The Junzao cultivar cultivated in the Hetian districts contained the soluble fiber content of 0.13 g/100 g FW, whereas the Akesu and Kashi harvested Junzao cultivars possessed 0.23 g/100 g FW soluble fiber content. The highest soluble fiber content in the Huizao cultivar was found in the Kashi district, whereas this cultivar contained less than 0.12 g/100 g FW soluble fiber content in the Akesu and Hetian districts.

Protein is a critical primary nutrient in fruits and its content plays an important role in the nutritional quality of jujube fruits (Kim et al., 2011; Pareek, 2013). In the present study, the protein content in these cultivars was comparable with the previous report (Zhou et al., 2013). In detail, the Dazao cultivar from the Hami district had the protein content of 3.97 g/100 g FW, and its protein content was higher than the other two cultivars (Table 1). The Junzao cultivar cultivated in these districts had the protein content ranging from 1.87 g/100 g FW to 3.06 g/100 g FW, whereas the Huizao cultivar contained the protein level of 2.36 g/100 g FW to 3.04 g/100 g FW. Additionally, the lowest protein content in the Junzao cultivar was found in the Hami district, whereas the Hetian district harvested Junzao fruits showed the highest protein level. Similarly, the Huizao cultivar in the Hetian district possessed the highest protein content compared to that harvested from the Akesu and Kashi districts.

The ash content in these cultivars harvested from these districts varied from 0.78 g/100 g FW to 1.10 g/100 g FW. This was consistent with the previous reports (Zhou et al., 2013). The Dazao cultivar showed the ash content of 1.05 g/100 g FW (Table 1). Regarding the Junzao cultivar, its ash content from the Hami and Akesu districts were above 1.0 g/100 g FW. However, the Kashi and Hetian harvested Junzao cultivars contained the ash content below 0.86 g/100 g FW. Similarly, the Huizao cultivar harvested in the Kashi district had the ash content about 0.80 g/100 g FW. However, the ash content of this cultivar cultivated in the Akesu and Hetian districts were higher than 1.0 g/100 g FW. These indicated that cultivation districts exerted a role in altering the ash content of the same jujube fruit cultivar.

Sugar is an important nutrient in jujube fruits and its content directly determines the sweetness of jujube fruits. Among these jujube fruit cultivars, their total sugar content remained similar. For example, the total sugar content in the Dazao cultivar in the Hami district was 30.23 g/100 g FW (Table 1). The Junzao cultivar harvested from the Hami, Akesu, Kashi, and Hetian districts contained the total sugar content ranging of 27.19 g/100 g FW to 30.56 g/100 g FW. Similarly, the Huizao cultivar in this study also had the total sugar content around 30 g/100 g FW. In addition, fructose, sucrose, and glucose were detected in all the jujube fruit cultivars in this study, which was consistent with the published reports (Guo et al., 2015a; Kao & Chen, 2015). Sucrose appeared to be the dominant soluble sugar in all the samples. Our result was as similar as the previous study (Chen et al., 2015c). It has been reported that sucrose is initially accumulated in the leaves of fruits, and it can be transferred from the fruit leaves to the fruit flesh. Afterwards, the fruit development process can further hydrolyze sucrose into glucose and fructose in fruit flesh, which results in the accumulation of the sweetness in jujube fruits (Bastos et al., 2016). The sucrose content in the Dazao cultivar was about 18 g/100 g FW. Regarding the Junzao cultivar, its sucrose content ranged of 16.98 g/100 g FW to 25.53 g/100 g FW, and these districts (except for the Hetian district) did not cause the significant difference on the sucrose content in the fruits. It should be aware that the Huizao cultivar in the Hetian district exhibited the highest sucrose content (25.8 g/100 g FW). However, the sucrose content in the Kashi district harvested Huizao cultivar was about 16.39 g/100 g FW. The sucrose content of the Huizao cultivar harvested from these three districts showed the significant differences. Similarly, the Dazao cultivar showed the fructose content of about 7 g/100 g FW. Its content in the Kashi district harvested Junzao cultivar was higher than 7 g/100 g FW, whereas the other Junzao cultivar samples had the fructose level about 4-5 g/100 g FW. In the Huizao cultivar, the highest fructose level was found in the Hetian district harvested cultivar, followed by that in the Kashi district and then the Akesu district. These different cultivars also exhibited the difference on the glucose content, and different districts affected the accumulation of glucose level in the same jujube cultivar.

Acid has been reported to be accumulated in fruits during the development, and its level tends to be decreased along with the maturation of fruits (Wu et al., 2012). In the present study, these cultivars harvested from different districts showed the total titratable acid level of 1.98 g/100 g FW to 3.12 g/100 g FW (Table 1). It has been accepted that the sugar-to-acid ratio is an important indicator to evaluate the quality of fruits and fruits with a high sugar-to-acid ratio tend to be preferred by consumers (Gao et al., 2014). The Dazao cultivar only had a 9.70 sugar-to-acid ratio. The sugar-to-acid ratio in the Huizao cultivar harvested from the Hami and Kashi districts were above 13, whereas the Hetian cultivated Huizao cultivar possessed a 10.2 sugar-to-acid ratio. The lowest sugar-to-acid ratio was found in the Junzao cultivar harvested in the Akesu district.

Ascorbic acid is a critical antioxidant in fruits, and it has been reported to scavenge free radicals through inhibiting the radical chain reactions (Hernández et al., 2016). Its accumulation in fruits is mainly determined by fruit genotype, cultivation condition, and management application (Koley et al., 2016). In this study, all the jujube fruits were rich in ascorbic acid (Table 1). For example, the ascorbic acid level in the Dazao cultivar was 185.46 mg/100 g FW. The Junzao cultivar contained the ascorbic acid content of 166.85 mg/100 g FW to 221.16 mg/100 g FW. Its level in the Huizao cultivar was from 162.50 mg/100 g FW to 244.58 mg/100 g FW. These cultivars showed the significant differences on the ascorbic acid level. In addition, different cultivation districts also showed the effect on the accumulation of ascorbic acid in the same jujube fruit cultivar. For instance, the highest ascorbic acid level in the Huizao cultivar was found in the Kashi district, followed by the Akesu and then the Hetian district. Similarly, the lowest ascorbic acid content in the Junzao cultivar was observed in the Hetian district.

Cyclic adenosine monophosphates (cAMP) are significant secondary messengers in plants that take charge of hormone and ion-channel signaling regulation through inactivating and/or activating relative enzymes (Cyong, 1981; Guo et al., 2015a). In the present study, a significant content difference on cAMP was observed in these Chinese jujube fruits (Table 1). More importantly, the districts effect appeared to be more obvious in the same jujube cultivar. For instance, the Dazao cultivar from the Hami district had the cAMP level of 37.65 μg/g FW. The cAMP level in the Junzao cultivar showed a significant variation, ranging of 50.48 μg/g FW to 87.50 μg/g FW. The lowest cAMP level found in the Huizao cultivar was from the Kashi district (20.35 μg/g FW). The rest districts harvested Huizao cultivars contained the cAMP level more than 37 μg/g FW.

Flavonoids are the important secondary metabolites in fruits, and these nutrients provide fruits with nutritional and sensory attributes (Hamood et al., 2016; Kang et al., 2010; Zhao et al., 2008b). These secondary metabolites are biosynthesized in fruits in response to the environmental stresses during the fruit development window, and they possess multiple health promoting properties (Zhang et al., 2015). It has been reported that the consumption of fruits rich in flavonoids can lower the risk of cardiovascular and chronic diseases (Knekt et al., 2002). In the present study, the Junzao cultivar exhibited higher level on the total flavonoids (48.90 mg/g to 62.72 mg/g), whereas the total falvonoids content in the Huizao cultivar was between 43.61 mg/g and 46.12 mg/g (Table 1). The Dazao cultivar was found to contain the total flavonoids level at 41.21 mg/g. More importantly, the total flavonoids content in the Junzao cultivar harvested from different cultivation districts appeared to be significantly different, which indicated that different districts with different climate conditions might play different stresses on the synthesis of flavnoids during the jujube fruit development. The similar observation was also found in the Huizao cultivar harvested from these districts.

3.2 Correlation analysis

Correlation analysis was carried out to investigate the correlation of these physical and chemical parameters in these jujube fruit cultivars (Table 2). The protein and the total dietary fiber content were significantly negatively correlated with the

Table 2. Correlation of fruit weight, fruit shape index, moisture, fiber, protein, ash, total sugars, fructose, sucrose, glucose, total acids, sugar-acid ratio, ascorbic acid, cAMP, total flavonoid contents of jujube cultivars.

	Fruit weight	Fruit shape index	Mc	Protein	Ash	TDF	IDF	SDF	Total sugars	Fructose	Glucose	Sucrose	Titratable acids	Sugar-to-acid ratio	AA	cAMP	Total flavonoids
Fruit weight	1.000																
Fruit shape index	-0.224	1.000															
Mc	0.585**	0.034	1.000														
Protein	-0.051	-0.883**	-0.195	1.000													
Ash	-0.064	0.013	-0.035	0.023	1.000												
TDF	-0.458*	-0.566**	-0.362	0.692**	0.434*	1.000											
IDF	-0.164	-0.156	0.235	0.014	0.138	0.376	1.000										
SDF	0.261	0.465*	0.629**	-0.554**	-0.359	-0.524**	0.253	1.000									
Total sugars	-0.415*	-0.157	-0.454*	0.232	0.220	0.271	-0.047	-0.425*	1.000								
Fructose	-0.470*	-0.182	-0.265	0.364	0.257	0.629**	0.035	-0.212	0.497*	1.000							
Glucose	-0.506*	0.142	-0.440*	0.049	0.165	0.318	-0.238	-0.189	0.482*	0.834**	1.000						
Sucrose	-0.255	-0.040	-0.639**	0.263	0.065	0.112	-0.665**	-0.625**	0.180	-0.054	0.179	1.000					
Titratable acids	-0.030	-0.319	0.109	0.544**	0.348	0.395	-0.180	-0.321	-0.108	0.128	-0.095	0.326	1.000				
Sugar-to-acid ratio	-0.101	0.271	-0.171	-0.455*	-0.268	-0.280	0.212	0.217	0.321	0.016	0.189	-0.306	-0.964**	1.000			
AA	0.070	0.307	0.156	-0.543**	-0.204	-0.219	0.592**	0.571**	-0.200	-0.102	-0.100	-0.750**	-0.650**	0.571**	1.000		
cAMP	0.537**	0.185	0.648**	-0.218	0.023	-0.484*	-0.322	0.270	-0.580**	-0.586**	-0.551**	0.093	0.334	-0.445*	-0.352	1.000	
Total flavonoid	0.498*	0.263	0.593**	-0.315	-0.457*	-0.760**	-0.476*	0.523**	-0.331	-0.394	-0.229	-0.069	-0.020	-0.083	-0.142	0.686**	1.000

**$p<0.01$; *$p<0.05$. Mc = moisture content; TDF = total dietary fiber; IDF = insoluble dietary fiber; SDF = soluble dietary fiber; AA = ascorbic acid.

fruit shape index. The fruit moisture content was positively correlated with the cAMP, total flavonoids, and soluble dietary fiber content in these fruits. Sucrose appeared to have a negative correlation with these components. Both the total dietary fiber content and total acids content exhibited a positive correlation with the protein content in these cultivars. However, a negative correlation of the protein content in these cultivars was established with the soluble dietary fiber and ascorbic acid content. It should be noted that the glucose and fructose levels in these cultivars were observed to be highly correlated to the total sugar content, whereas higher sugar content in these cultivars resulted in a low level of the cAMP content in these cultivar samples. The glucose content in these jujube fruits appeared to be positively correlated to the fructose level but negatively related with the cAMP content. High total titratable acid content resulted in a decrease on the sugar-to-acid ratio and the accumulation of ascorbic acid in these jujube fruits. A positive correlation was established between ascorbic acid and the sugar-to-acid ratio in the fruits, whereas the correlation between ascorbic acid and the cAMP level in these samples was found to be negative.

3.3 Principal component analysis

To investigate the effect of jujube genotype and cultivation districts on the similarity of the jujube quality, principal component analysis was carried out in this study using all the detected physical and chemical parameters as the variables (Figure 1). The first three principal components were extracted to represent more than 74% of the total variance. In detail, the first principal component (PC1) accounted for about 34% of the total variance, and it mainly consisted of the total dietary fiber, protein, total sugar, fructose, glucose, sucrose, and total titratable acids. Meanwhile, the total soluble dietary fiber, total flavonoids, and moisture content also showed the impact on the PC1. The second principal component (PC2) represented 25% of the total variance, and it was significantly affected by the level of the sugar-to-acid, ascorbic acid, and cAMP in the jujube fruits. The third principal component (PC3) was mainly comprised of the total insoluble dietary fiber, and it accounted for 15% of the total variance.

The difference on the quality of these jujube fruits cultivated in different districts is shown in Figure 2. It was found that the jujube fruit genotype played a primary role in the determination of the jujube fruit quality. For instance, the Junzao cultivars harvested from these districts were placed at the negative scale of the PC1, which was mainly attributed to its relatively low level on the total dietary fiber, protein, total sugar, and total titratable acids. The Huizao cultivars were aggregated near or on the positive scale of the PC2, and these different districts harvested cultivars were also significantly impacted by the PC3. They possessed the mediate level of the sugar-to-acid ratio and ascorbic acid. The Dazao cultivar in the Hami district was positioned at the positive side of the PC3, which resulted mainly from its high level of the total dietary fiber, protein, sugar, and the total acids. Additionally, the districts effect was also found

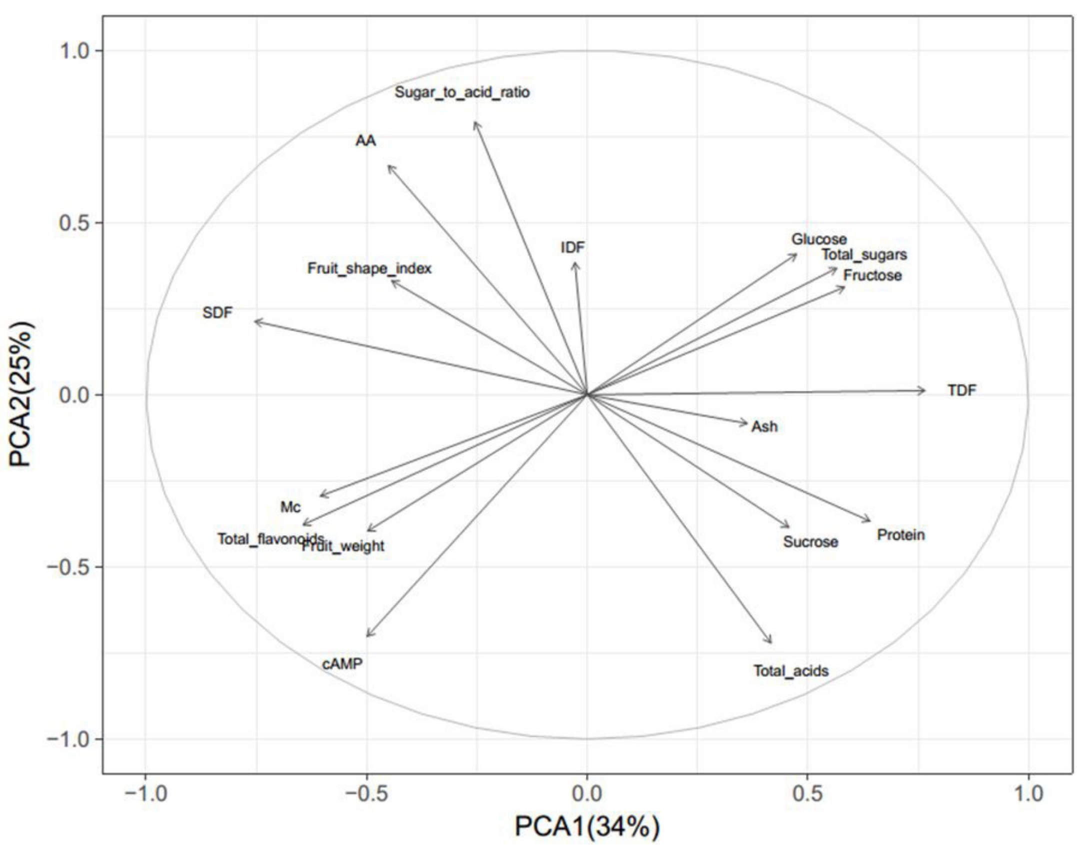

Figure 1. Loading matrix of principal components to the quality characteristics of jujube.

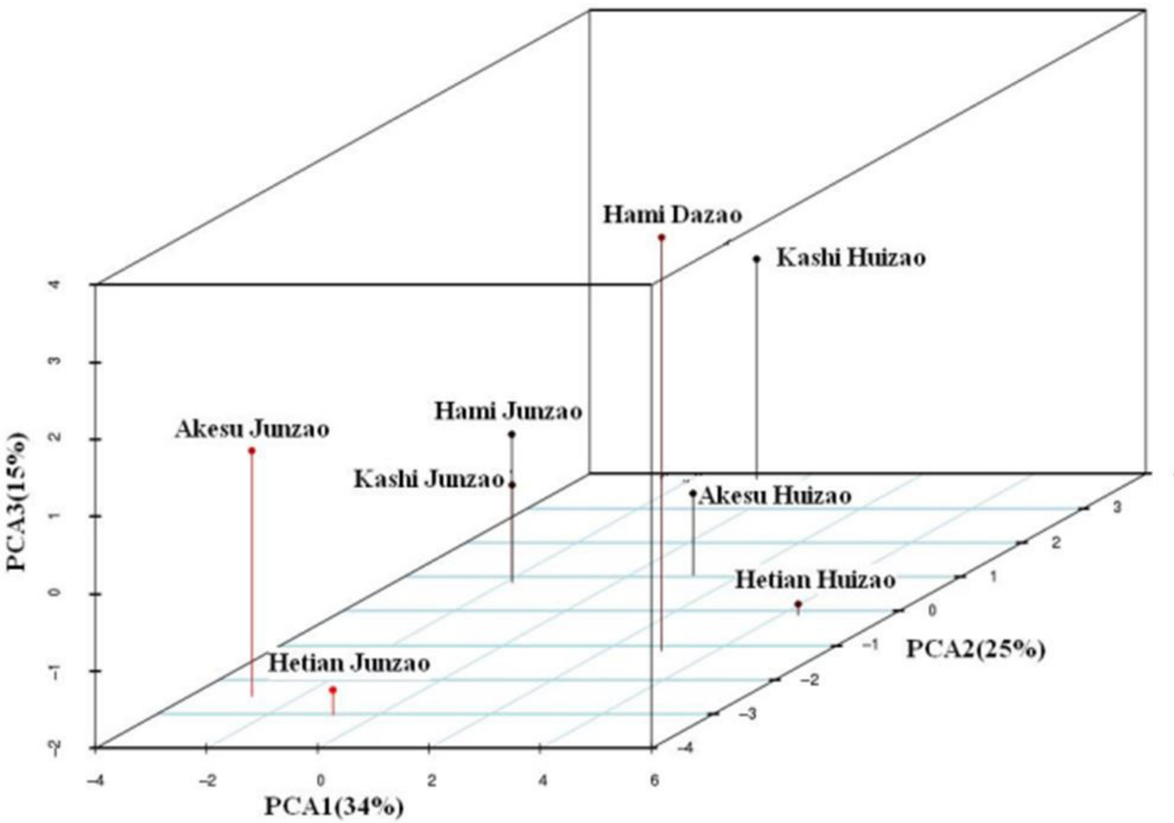

Figure 2. Principal component scores after standardization.

in the same jujube cultivar. For example, the Junzao cultivar harvested in the Hami and Kashi districts were positioned in the positive scale of the PC2, whereas the Akesu and Hetian district cultivated Junzao cultivars were at the negative portion of the PC2. Such segregations were mainly due to the difference on the level of the sugar-to-acid ratio and ascorbic acid in this cultivar from different districts. Similarly, the Huizao cultivar in the Kashi area had the highest total soluble dietary fiber, which resulted in this cultivar separated from that harvested in the Akesu and Hetain districts.

4 Conclusion

In conclusion, three jujube cultivars harvested in four districts of the Xinjiang region were compared in terms of their physical and chemical properties. These jujube cultivars exhibited different physicochemical indexes, and the same cultivar harvested from different districts showed the difference on these parameters. These physical and chemical properties in jujube fruits exhibited positive and/or negative correlations as confirmed by the correlation analysis. Principal component analysis indicated that district conditions affected the accumulation of these parameters in jujube fruits.

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