Jujube Cultivar Vitamin C Profile and Nutrient Dynamics during Maturation

Junxin Huang

Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003

Robert Heyduck

Sustainable Agriculture Science Center at Alcalde, New Mexico State University, Alcalde, NM 87511

Richard D. Richins¹

Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003

Dawn VanLeeuwen

Economics, Applied Statistics and International Business Department, New Mexico State University, Las Cruces, NM 88003

Mary A. O'Connell

Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003

Shengrui Yao¹

Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003; and Sustainable Agriculture Science Center at Alcalde, New Mexico State University, Alcalde, NM 87511

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Abstract. Vitamin C profiles of 46 jujube cultivars were assessed from 2012 to 2015, and fruit nutrient dynamics of 10 cultivars during maturation were examined from 25 Aug. to 7 Oct. 2014 at 2-week intervals at New Mexico State University's Alcalde Sustainable Agriculture Science Center and Los Lunas Agricultural Science Center. This is the first report in the United States profiling Vitamin C in jujube cultivars. The vitamin C content of mature fruit of 45 (of 46) cultivars ranged from 225 to 530 mg/100 g fresh weight (FW) plus 'Youzao' having the highest content of 820 mg/100 g FW at early mature stage. In general, drying cultivars had higher vitamin C content than fresh-eating cultivars whereas 'Jinsi' series (multipurpose) had relatively higher vitamin C content than others (>400 mg/100 g FW). Fruit vitamin C and moisture content decreased significantly during the maturation process. The average vitamin C contents of nine cultivars at Alcalde decreased more than 40% based on FW from 25 Aug. to 7 Oct. To maximize the vitamin C benefit, the ideal stage to consume fresh-eating cultivars is the creamy stage. Titratable acidity and soluble solids increased significantly during maturation. In mature jujubes, the titratable acidity and soluble solids ranged between 0.27% to 0.46% and 27.2% to 33.7%, respectively. Glucose, fructose, and sucrose content also rose significantly during ripening. Mature fruits contained 31–82 mg/g FW glucose, 32–101 mg/g FW fructose, and 53–159 mg/g FW sucrose among the cultivars tested. Based on sucrose contents, cultivars can be divided into two groups, "high-sucrose" (more sucrose than glucose or fructose) and "low-sucrose" (less sucrose than glucose or fructose). 'Dagua', 'Honeyjar', 'Lang', 'Li', 'Maya', 'Sugarcane', and 'Sherwood' belong to the "high-sucrose" group. Total phenolic content and 2,2-diphenyl-1-picrylhydrazyl (DPPH)-reducing capacity in fruit decreased during maturation, and the total phenolic content of mature jujube was 12–16 mg gallic acid equivalent (GAE)/g dry weight (DW). For mature fruit, 'Li' and 'Li-2' had the highest DPPH-scavenging efficiency whereas 'Sugarcane', 'So', and 'Lang' had the lowest at Alcalde, NM.

Jujube (*Ziziphus jujuba* Mill.) originated in China and has been cultivated there for more than 4000 years (Guo and Shan, 2010; Liu, 2006; Qu, 1963; Yao, 2013), playing an important role in traditional Chinese medicine (Wu et al., 2013). Jujube was introduced to Europe through the "Silk Road" in the

early Christian era (Liu, 2006; Lyrene, 1979; Yao, 2013). Jujube seedling plants were first introduced from Europe to the United States in 1837 (Rehder and Rixford, 1929; Yao, 2013). Currently jujubes are widely distributed in the United States from Pennsylvania, south to Florida and then west through

Georgia, Tennessee, and along the southern tier of states all the way to California (Ashton, 2006; Brubaker, 1977; Locke, 1948; Lyrene and Crocker, 1994; Yao, 2013). Jujube is a crop which is able to withstand severe water deficits (Hager and Edward, 1989) and thus grows and produces well in the southwest United States.

In commerce, two types of jujube can be commonly found: fresh jujube consumed as fruits, and dried jujube used for snacks, cooking as a food additive and flavoring, or as a Chinese herb (Gao et al., 2013; Chen et al., 2013). Jujubes are recognized as a functional food because they have high nutritional and medicinal values (Zhao et al., 2008).

The main biologically active components of jujube fruit are vitamin C (ascorbic acid), polyphenols such as phenolic acids and flavonoids, triterpenic acids, and polysaccharides. Jujube is also rich in fiber, organic acids, and volatile compounds which provide a pleasant aroma (Cao et al., 2011; Gao et al., 2013).

Jujube fruit is considered a rich source of vitamin C and has been called a natural "vitamin C pill" (Guo and Shan, 2010; Liu, 2006). Sugar content is one of the main quality indicators of jujube fruits (Shi et al., 2005). The sugar content of fresh mature jujube can reach 30%, which is 2–3 times the sugar content of citrus and peach, and two times the sugar in pear and apple (Gan et al., 2000). Jujube is also high in antioxidants, with its total phenolic content higher than that of cherries, guava, and red grapes (Carlsen et al., 2010; Gao et al., 2013). Jujube phenolic extracts can prevent hemolysis and lipid peroxidation in erythrocytes and are a source of antioxidants (Cao et al., 2011).

The New Mexico State University (NMSU) Sustainable Agriculture Science Center at Alcalde has imported and collected more than 50 jujube cultivars (Yao, 2013, 2016; Yao et al., 2015), and cultivar trials have been set up at four NMSU agricultural science centers in New Mexico. The objective of this study was to assess the nutrient dynamics during jujube fruit maturation and the differences among cultivars for nutrient characteristics including vitamin C content, titratable acidity, moisture content, soluble solids content, sugar composition, total phenolic content, and DPPH-scavenging efficiency.

Materials and Methods

Experiment 1: fruit nutrient dynamics

Locations and plant materials. The jujube study was conducted at two locations: New Mexico State University's Sustainable Agriculture Science Center at Alcalde (lat. 36°05'28" N, long. 106°03'25" W, and 1737-m elevation) and Agricultural Science Center at Los Lunas (lat. 34°46'0" N, long. 106°45'32" W, and 1475-m elevation). Ten cultivars with trees ranging from 2 to 8 years old were used at Alcalde, NM: 'Dagua', 'Honeyjar', 'Lang', 'Li', 'Li-2', 'Maya',

'September Late', 'Shuimen', 'So', and 'Sugarcane'. Sprinkler, drip, or flood irrigation was employed once per week or as necessary at the Alcalde location. Five cultivars—GA866, Lang, Li, Sherwood, and Sugarcane—were from Los Lunas, NM, and ranged from 7 to 8 years old and '(Y) Lang' (Lang young tree) was 3 years old. At Los Lunas, flood irrigation was employed every 2 weeks. 'Li', 'Lang', and 'Sugarcane' were grown at both locations.

Harvest and handling. Fruits from each cultivar were harvested on 25 Aug., 9 Sept., 24 Sept., and 7 Oct. On 7 Oct., fruits from Los Lunas were overmature, and at Alcalde, 'Shuimen' did not have enough fruits for analysis. Fifteen to twenty fruits from each tree (replicate) were collected. Cultivars Dagua, Honeyjar, September Late, So, Sugarcane, (Y) Lang, and Li had three trees with fruit available for nutrient analysis. Fruits harvested in Los Lunas were kept in a cooler with ice and transported for 2 h back to the laboratory in Alcalde. Tests of vitamin C content, titratable acidity, moisture content, and soluble solids content were conducted with fresh fruits within 72 h after harvest. The rest of the fruits were cut and homogenized into small pieces by a food processor after core removal. Small pieces were put into 50-mL plastic tubes and then frozen in liquid nitrogen. Tubes with frozen fruit pulp were transported on ice to the laboratory at the NMSU Las Cruces campus and kept in the freezer at -80°C until lyophilized (Labconco Corp, Kansas City, MO). The lyophilized jujube powders were kept at -80°C until the nutrient tests were performed.

Vitamin C. Vitamin C content was measured by the titration of 2,6-dichlorophenol-indophenol, following Bessey (1933) with slight adjustments. Fresh jujube slices (5 g) including two slices from opposite sides of each fruit were ground with sterile sand and brought up to 50 mL with 2% oxalic acid. The sample was clarified by centrifuging at 4000 rpm for 10 min at 4°C (Eppendorf 5810R; Hauppauge, NY), and 5 mL of the supernatant was titrated with 0.2 mg/mL 2,6-dichlorophenol-indophenol. Two titrations were done for each replicate. Vitamin C was calculated as mg/100 g FW.

Titratable acidity. Titratable acidity was measured by the visual titration of sodium hydroxide with phenolphthalein as the indicator. Jujube slices (5 g) were ground and poured into a 100-mL volumetric flask with

40 mL of deionized water, and maintained at 80°C for 30 min in a water bath. The sample was then brought to 100 mL with water, 50 mL of which was centrifuged at 4000 rpm for 10 min at 4°C . The supernatant (15 mL) was titrated with 0.01 N solution of sodium hydroxide, with two replicates for each sample.

Moisture content. Moisture content of jujube fruit was measured by the weight difference after drying in an oven (VWR International, Radnor, PA). About 10 g of fruit slices from each cultivar was put into the oven at 65°C until the weight was constant. Measurements were recorded as % moisture of FW.

Soluble solids content. Soluble solids content (%) was measured by a digital refractometer (Atago digital pocket refractometer; Bellevue, WA).

Sugar composition. Sugar composition (glucose, fructose, and sucrose) of jujube fruit was determined by the enzymatic method following Revanna et al. (2013) with slight adjustments and expressed in mg/g FW. Prefrozen jujube slices were lyophilized (Labconco Corp) at -75°C for 3 d, ground into powder by a micro hammer (Glen Mills Inc., Clifton, NJ) and filtered through a 0.5-mm sieve. Extracts for analysis were generated from lyophilized jujube powder, 20 mg per sample, in triplicate.

Total phenolic content. Total phenolic content of jujube fruit was determined according to Xue et al.'s method (2009) with some modifications. Extracts for analysis were generated from lyophilized jujube powder, 0.2 g in 12 mL of 70% methanol per sample. The analyses were conducted on all cultivars harvested on 9 Sept. for both locations and all cultivars harvested on 7 Oct. except for 'Shuimen' at Alcalde. Analyses of each sample were carried out in triplicate and recorded as mg of GAE/g DW.

2,2-diphenyl-1-picrylhydrazyl (DPPH)-scavenging efficiency. The DPPH radical-scavenging effects of jujube samples were measured following Choi et al.'s method (2011) with some modifications. The jujube phenolic extracts prepared to measure total phenolic content were used to make five dilutions (10–500 $\mu\text{g/mL}$) for analysis. The DPPH-scavenging efficiency (%) was expressed as concentration ($\mu\text{g/mL}$) of lyophilized jujube powders needed to decrease the initial DPPH radical concentration by 50% (EC_{50}). The analyses were conducted on all cultivars harvested on 9 Sept. and all cultivars except for 'Shuimen' on 7 Oct. at Alcalde. Analyses of each sample were carried out in triplicate with triplicates averaged.

Experiment 2: vitamin C profile of 46 jujube cultivars at NMSU alcalde. The mature jujube fruit vitamin C profiles were conducted at the NMSU Alcalde Center from 2012 to 2015 with 46 cultivars of varied tree ages (2–9 years old). Sampling dates were from late September to early October each year with 15–30 fruit per cultivar depending on fruit size. The fruit development stage varied from half creamy/half brown to full

brown stage with the exception of 'Youzao', which was creamy or slightly colored stage at the time of sampling. Cultivars sampled for these analyses varied from year to year, and the details are listed in Table 1. Vitamin C was measured using the same method as described for Experiment 1. For most cultivars, because of fruit availability, especially from 2012 to 2013, one tree per cultivar was used for this analysis. In 2014–15, a few cultivars had two trees (two replicates), and the averages are listed in the table.

Statistical analysis. Statistical analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC, 2002–13) software. The significance level was set at $P = 0.05$. For Experiment 1, fruit-quality parameters (vitamin C content, titratable acidity, soluble solids, moisture content, total phenolic content, and DPPH-scavenging efficiency), a mixed model was fitted. Because the design had missing cells, the model included a single fixed effect with levels corresponding to location, cultivar, and harvest time combinations that were present in the data. To account for repeated measures and subsampling, the model included random effects for tree within location and cultivar, and the time $\times$ tree within location and cultivar interaction. The outlier strategy was used to assess sensitivity of findings to extreme values, and analyses with the outliers removed are presented only when there were differences between the findings with all data and with the outliers removed (Ramsey and Schafer, 1997). Outliers were defined as having Pearson residuals with magnitude greater than 2. Because for some variables, random effects were estimated to be zero which impacted denominator df computation, we used a relatively conservative denominator df of 15, which was obtained by $(2-1) + 7 \times (3-1)$, as there were eight location-cultivar combinations represented by one tree, one location-cultivar represented by two trees, and seven location-cultivar represented by three trees. To compare location-cultivar combinations at each time and time within each cultivar-location combination, slices of time cultivar-location were obtained; when a slice was significant, follow-up pairwise comparisons were conducted.

Because not all cultivars were profiled for vitamin C each year in Experiment 2, the repeated measurements among years analyzed were used as replicates to calculate the standard error for each cultivar.

Results

Vitamin C profile of 46 jujube cultivars

The vitamin C content of 45 (of 46) mature jujube cultivars at NMSU Alcalde Center ranged from 225 to 530 mg/100 g FW and 820 mg/100 g FW for 'Youzao' at creamy stage or slightly colored stage (Table 1). Table 1 also lists the cultivar uses as fresh eating, drying, or multipurpose. In general, fresh-eating cultivars had lower vitamin C than others whereas the three

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¹Corresponding author. E-mail: yaos@nmsu.edu.

Table 1. Fruit vitamin C contents (mg/100 g FW) of 46 jujube cultivars at mature stage or as indicated in the table at Alcalde, NM, from 2012 to 2015. The last nine cultivars in the table had 1 year result, for reference only.

Cultivar	Uses ^z	24 Sept. 2012	5 Oct. 2012	1 Oct. 2013	8 Oct. 2013	30 Sept. 2014	6 Oct. 2015	AVG	SE ^y
Shuimen	M	245.3 ^{50x}	234.4		211.6		211.6	225.7	9.76
GI-1183	M					264.6	226.5	245.5	26.94
Alcalde-1	F			266.7		256.1		261.4	7.50
Gaga	F		357.0	230.5	211.6	258.2	258.2	263.1	28.05
Dabailing	F				306.1 ⁸⁰	306.9	274.6	295.9	13.03
Dagua	F			262.3 ⁴⁰	328.6 ⁸⁰	319.6	274.1	296.2	18.94
September late2	M					312.2 ³⁰	284.1 ⁵⁰	298.2	19.87
Jixin	D				298.0	325.9	278.3	300.7	16.92
Redland	F		314.0		325.2	281.5	300.5	305.3	10.85
Li	F	283.9			308.8 ⁸⁰	322.7	320.6	309.0	10.29
Shanxi Li	F		294.6		315.0 ⁸⁰	322.0 ³⁰	320.6	313.1	7.31
Maya	F	335.1	359.1	311.0	273.5		307.4	317.2	16.06
Honeyjar	F	333.7 ⁵⁰		343.7	298.0			325.1	17.01
ZCW	F/M					352.4 ³⁰	298.4	325.4	38.16
Li-2	F	332.3 ¹⁰	318.3				348.1	332.9	10.54
Sihong	M		348.4		336.7		330.2	338.4	6.53
Don P	D	350.8		325.7			341.8	339.4	8.99
Lang	D	366.8		310.6			366.1	347.8	22.81
So	O	359.4 ⁶⁰			378.9		310.1	349.4	25.09
Jing-39	F					364.0 ^C	345.0 ⁵⁰	354.5	13.47
Jinchang	D	366.5 ⁶⁰		349.9		342.9 ⁵⁰	364.0	355.8	6.53
Chaoyang	M	378.6		341.6				360.1	26.13
Junzao	D	381.5 ⁴⁰			373.5	335.9		363.6	17.20
Pitless	M			366.3	371.5			368.9	3.68
Dragon	O				349.0		396.8	372.9	33.83
Sugarcane	M	373.6		378.9	374.1			375.6	2.07
Sherwood	M					413.8 ³⁰	369.3 ³⁰	391.6	31.47
LYX	F/M	426.4 ⁵⁰			391.2	406.3		408.0	12.49
KFC	F/M				387.8 ⁷⁰	451.9	427.6	422.4	22.89
Jinsi-2	M	442.1 ⁷⁰					425.4	433.7	11.78
Jinkuiwang	M				423.1 ⁶⁰		477.8	450.5	38.68
Zhongning	M			428.9	477.8		488.4	465.0	22.45
Jinsi-4	M	531.5 ⁴⁰	576.3		408.8 ⁸⁰	438.1	440.2	479.0	35.65
Jinsi-3	M	453.5 ³⁰	479.6 ⁸⁰		505.4		482.5	480.3	12.28
Abbeville	X	488.4 ⁴⁰	522.6				438.1 ⁶⁰	483.0	30.06
Xiang	D				497.3 ²⁰	561.9 ³⁰		529.6	45.70
Youzao ^z	D		789.2 ^C			848.7 ²⁰		819.0	42.02
Teapot	O				312.9 ⁴⁰			312.9	
Jin	X						348.1	348.1	
Xingguang	D	372.5						372.5	
Globe	D						383.1	383.1	
Fitzgerald	X						422.2	422.2	
Mushroom	O				436.7			436.7	
Miyunxiaozao	M	479.1						479.1	
Topeka	X						480.4	480.4	
Yuanlingzao	D		503.2					503.2	

^zFruit uses from our preliminary results: F = fresh eating cultivar; D = drying cultivar; M = multipurpose (both fresh eating and drying); O = ornamental; X = not enough data to decide (too late at Alcalde, poor fruit quality, or have not been tested for drying yet).

^ySE = standard error.

^xThe superscript letter or number indicates the fruit developing stages: 10 = 10% red color on average; 20 = 20% red color on average; 30 = 30% red color on average; 40 = 40% red color on average; 50 = 50% red color on average; 60 = 60% red color on average; 70 = 70% red color on average; 80 = 80% red color on average; c = creamy color stage; no letter/number = 90% to 100% red color, mature fruit.

cultivars with more than 500 mg/100 g FW vitamin C were drying only cultivars—Yuanlingzao, Xiangzao, and Youzao. Vitamin C content for each cultivar varied slightly by year and harvest date, but there was a clear trend. The lower-end ones were always low, and the higher-end ones are always high, and the order of those in the middle may change slightly from year to year.

Cultivar Shuimen had the lowest vitamin C content among all cultivars tested at Alcalde whereas ‘Youzao’ had the highest. Some of the multipurpose cultivars, such as ‘Jinsi’ series (‘Jinsi-2’, ‘Jinsi-3’, ‘Jinsi-4’, ‘Miyunxiaozao’, and ‘JKW’), ‘LYX’, and ‘KFC’, were also high in vitamin C (>400 mg/100 g FW).

Nutrient dynamics during jujube fruit maturation

Within the same location, timing of maturation varied among cultivars. For the same cultivar, the timing of maturation changed at different locations. Figure 1 shows ‘Li’ and ‘Sugarcane’ samples from both Los Lunas and Alcalde. During maturation, fruit skin color changed from green to light green/creamy, to half creamy/half brown and then to full brown/red stage. Jujube fruit maturation at Los Lunas was roughly 2 weeks earlier than at Alcalde (Fig. 1).

Vitamin C. Vitamin C content of jujube fruit decreased during fruit maturation with the highest content in green fruit stage (Table 2), which was highly consistent for all cultivars at both locations. Vitamin C

content varied among cultivars similar to that reported above with ‘Lang’ as the highest which is a drying cultivar. The average vitamin C content of nine cultivars (without ‘Shuimen’) at Alcalde decreased from 536.5 to 313.5 mg/100 g FW within 6 weeks (25 Aug. to 7 Oct.). On the same dates, the vitamin C content of fruits at Alcalde tended to be higher than at Los Lunas, mainly because of advanced season at Los Lunas compared with Alcalde.

Titrateable acid. The titrateable acidity increased during fruit maturation, and this trend was consistent with all cultivars at both locations (Table 3). At Alcalde, the average titrateable acidity of all cultivars harvested on 25 Aug., 9 Sept., 24 Sept., and 7 Oct. were 0.19%, 0.22%, 0.32%, and 0.38%, respectively.

Fig. 1. 'Li' and 'Sugarcane' samples from Los Lunas and Alcalde, NM at different sampling dates in 2014.

Table 2. Vitamin C content (mg/100 g FW) of different jujube cultivars in 2014 at both Alcalde and Los Lunas, NM.

Location	Cultivar	No of trees ^z	25 Aug.	9 Sept.	24 Sept.	7 Oct.	SE ^y
Alcalde	Dagua	3	541.3 cA ^x	347.8 deB	315.9 deC	308.8 bcdC	10.1
	Honeyjar	1	540.2 bcA	338.8 deB	323.1 bcdeBC	286.7 cdeC	17.5
	Lang	2	544.5 bcA	412.8 abB	379.3 aC	356.8 aC	13.6
	Li	1	529.4 cA	331.5 defB	289.9 eBC	263.7 eC	17.5
	Li-2	1	659.5 aA	455.5 aB	340.6 abcdC	312.5 abcdeC	17.5
	Maya	3	576.5 bA	385.9 bcB	321.1 cdeC	325.6 abcC	10.1
	September Late	3	479.0 dA	335.3 eB	312.2 deBC	291.4 deC	10.1
	Shuimen	2	432.0 eA	279.1 gB	235.9 fC	N/A ^w	13.6
	So	3	541.9 cA	400.2 bB	348.4 abcC	335.1 abC	10.1
	Sugarcane	3	520.3 cA	393.2 bcB	364.5 aC	340.9 aC	10.1
Los Lunas	(Y) Lang	3	436.3 eA	371.1 cdB	368.3 aB	N/A	10.1
	GA866	1	356.8 fA	293.6 fgB	240.6 fC	N/A	12.0
	Lang	2	387.9 fA	330.8 eB	375.0 aA	N/A	10.7
	Li	3	359.4 fA	289.9 gB	248.8 fC	N/A	10.1
	Sherwood	1	531.5 cA	402.8 bcB	357.9 abC	N/A	12.0
	Sugarcane	1	349.8 fA	340.2 deA	292.5 deB	N/A	17.5

^zNo. of trees referred to the number of separate trees from which samples were collected for each cultivar. 'Sherwood', 'Li', 'Lang', and '(Y) Lang' at Los Lunas, 'Dagua', 'Maya', 'Sugarcane', 'So', and 'September Late' at Alcalde had three replicates.

^ySE referred to the standard error.

^xThe average vitamin C contents with different lowercase letters within a column are significantly different. The average vitamin C contents with different capital letters within a row are significantly different.

^wCultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

At Los Lunas, the average titratable acidity on 25 Aug., 9 Sept., and 24 Sept. were 0.17%, 0.21%, and 0.29%, respectively. The greatest increase appeared from 9 Sept. to 24 Sept. at both locations. At Alcalde on 24 Sept. and

7 Oct., 'Dagua', 'Li', and 'September Late' ranked low whereas 'So' and 'Maya' ranked the highest on 7 Oct. at the most-mature stage.

Moisture content. The moisture content of jujube fruit generally decreased as it matured,

which was consistent across all cultivars at both locations (Table 4). At Alcalde, the average moisture content of all cultivars harvested on 25 Aug., 9 Sept., 24 Sept., and 7 Oct. were 86.0%, 82.9%, 75.1%, and 67.4%, respectively. The average moisture content at Los Lunas on 25 Aug., 9 Sept., and 24 Sept. were 82.8%, 75.2%, and 66.8%, respectively. Comparison of the three common cultivars ('Lang', 'Li', and 'Sugarcane') at both locations indicated that the season at Los Lunas was roughly 2 weeks ahead of Alcalde.

Soluble solids. Fruit soluble solids contents (%) increased during maturation (Table 5). The average soluble solids content of jujube increased from 12.4% (9 Sept.) to 30.8% (7 Oct.) at Alcalde, and climbed from 19.8% (9 Sept.) to 29.1% (24 Sept.) at Los Lunas. Soluble solids content was negatively correlated to the moisture content ($R^2 = 0.8156$ for cultivars at both locations on 24 Sept. and 7 Oct.). Cultivars with higher soluble solids content tended to have lower moisture content.

Sugar composition.

Glucose. The glucose content (mg/g FW) of fruits from most cultivars at both locations increased during maturation (Fig. 2). The average glucose content of all cultivars climbed from 29.8 mg/g FW (25 Aug.) to 70.2 mg/g FW (7 Oct.) at Alcalde, and increased from 35.8 mg/g FW (25 Aug.) to 55.4 mg/g FW (24 Sept.) at Los Lunas. At mature stage (7 Oct.), cultivars ranked from high to low were as follows: 'Li-2', 'Sugarcane', 'Li', 'So', 'Maya', 'September Late', 'Lang', 'Dagua', and 'Honeyjar' at Alcalde. At Los Lunas, the glucose content of 'GA866', 'Li', and 'Sugarcane' climbed significantly during maturation, whereas '(Y) Lang', 'Lang', and 'Sherwood' remained the same from 9 Sept. to 24 Sept. Cultivars ranked from high to low as follows: 'GA866', 'Sugarcane', 'Li', '(Y) Lang', 'Lang', and 'Sherwood' on 24 Sept.

Fructose. The average fructose content in jujubes of all cultivars rose from 41.3 mg/g FW (25 Aug.) to 65.2 mg/g FW (7 Oct.) at Alcalde, and climbed from 48.2 mg/g FW (25 Aug.) to 54.8 mg/g FW (24 Sept.) at Los Lunas (Fig. 3). At Alcalde, during maturation, the fructose content increased but the rate varied with cultivars (Fig. 3). For 'Sugarcane', it increased slowly at the beginning and dropped from 24 Sept. to 7 Oct. The fructose content of 'September Late' and 'So' increased dramatically from 24 Sept. to 7 Oct. Cultivars ranked from high to low as follows: 'September Late', 'So', 'Li-2', 'Lang', 'Li', 'Dagua', 'Honeyjar', 'Maya', and 'Sugarcane' on 7 Oct., 'Maya' and 'Sugarcane' had relatively low fructose content on all harvest dates. At Los Lunas, cultivars ranked from high to low of fructose content as follows: 'GA866', 'Li', 'Sugarcane', 'Lang', '(Y) Lang', and 'Sherwood' on 24 Sept. 'Sherwood' had the lowest rank on all three harvest dates.

Sucrose. Sucrose content of most cultivars climbed greatly from 24 Sept. to 7 Oct. (Fig. 4). The average sucrose content of all

Table 3. Titratable acidity (%) dynamics of different jujube cultivars in 2014 both at Alcalde and Los Lunas, NM.

Location	Cultivar	No. of trees ^z	25 Aug.	9 Sept.	24 Sept.	7 Oct.	SE ^y
Alcalde	Dagua	3	0.15 eB ^x	0.18 defB	0.27 ghA	0.27 fA	0.01
	Honeyjar	1	0.27 aBC	0.24 abcdC	0.33 cdefAB	0.37 deA	0.02
	Lang	2	0.16 cdeC	0.17 efgC	0.30 efgB	0.39 cdA	0.02
	Li	1	0.14 eC	0.23 bcdeB	0.24 hiB	0.32 efA	0.02
	Li-2	1	0.22 abcB	0.19 cdefgB	0.39 abA	0.44 abcA	0.02
	Maya	3	0.23 abD	0.29 aC	0.37 abcB	0.46 aA	0.01
	September Late	3	0.15 eC	0.14 gC	0.28 ghB	0.36 deA	0.01
	Shuimen	2	0.21 abcdB	0.25 abcB	0.34 cdeA	N/A ^w	0.02
	So	3	0.20 bcC	0.21 cdeC	0.39 aB	0.45 aA	0.01
	Sugarcane	3	0.21 bcD	0.26 abC	0.32 defB	0.40 bcA	0.01
	(Y) Lang	3	0.16 eC	0.22 bcdeB	0.34 bcdA	N/A ^w	0.01
	GA866	1	0.15 eC	0.20 cdefB	0.29 fghA	N/A	0.02
Los Lunas	Lang	2	0.21 abcB	0.23 bcB	0.37 bcdA	N/A	0.01
	Li	3	0.17 cdeB	0.21 cdeB	0.25 hA	N/A	0.01
	Sherwood	1	0.16 deB	0.16 fgB	0.21 iA	N/A	0.02
	Sugarcane	1	0.19 bcdeB	0.23 abcdeB	0.30 defgA	N/A	0.02

^zNo. of trees referred to the number of separate trees from which samples were collected for each cultivar. 'Sherwood', 'Li', 'Lang', and '(Y) Lang' at Los Lunas, 'Dagua', 'Maya', 'Sugarcane', 'So', and 'September Late' at Alcalde had three replicates.

^ySE referred to the standard error.

^xThe average titratable acidity with different lowercase letters within a column are significantly different. The average titratable acidity with different capital letters within a row are significantly different.

^wCultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

Table 4. Moisture content (%) dynamics of different jujube cultivars in 2014 at both Alcalde and Los Lunas, NM.

Location	Cultivar	No. of trees ^z	25 Aug.	9 Sept.	24 Sept.	7 Oct.	SE ^y
Alcalde	Dagua	3	87.1 abA ^x	84.1 abB	76.7 abcC	69.6 aD	1.2
	Honeyjar	1	86.5 abcA	88.8 aA	76.6 abcdB	68.3 abcC	2.0
	Lang	2	85.1 abcA	82.2 bcA	70.4 efgB	64.5 bcC	1.8
	Li	1	85.7 abcA	82.3 bcA	75.5 abcdeB	66.9 abcC	2.0
	Li-2	1	85.1 abcA	82.2 bcA	72.8 cdefB	69.3 abB	2.0
	Maya	3	85.8 abA	80.9 bcB	72.2 defC	64.2 cD	1.2
	September Late	3	85.6 abA	84.1 abA	79.5 aB	66.8 abcC	1.2
	Shuimen	2	84.0 bcfA	78.8 cdeB	72.2 cdefC	N/A ^w	1.8
	So	3	86.7 abA	82.9 bcB	79.3 abC	70.1 aD	1.2
	Sugarcane	3	88.8 aA	82.6 bcB	75.9 bcC	66.7 abcD	1.2
	(Y) Lang	3	82.0 cA	74.0 fB	66.3 ghiC	N/A	1.2
	GA866	1	83.4 bcA	75.2 defB	64.7 hiC	N/A	1.7
Los Lunas	Lang	2	81.4 cA	73.0 fB	68.9 fghC	N/A	1.3
	Li	3	83.7 bcA	76.0 defB	65.0 iC	N/A	1.2
	Sherwood	1	84.2 bcA	79.5 cdB	69.5 fghC	N/A	1.7
	Sugarcane	1	82.35 bcA	73.41 efB	66.28 ghiC	N/A	2.0

^zNo. of trees referred to the number of separate trees from which samples were collected for each cultivar. 'Sherwood', 'Li', 'Lang', and '(Y) Lang' at Los Lunas, 'Dagua', 'Maya', 'Sugarcane', 'So', and 'September Late' at Alcalde had three replicates.

^ySE referred to the standard error.

^xThe average moisture contents with different lowercase letters within a column are significantly different. The moisture contents with different capital letters within a row are significantly different.

^wCultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

cultivars increased from 34.2 mg/g FW (25 Aug.) to 85.3 mg/g FW (7 Oct.) at Alcalde, and climbed from 48.8 to 113.2 mg/g FW (24 Sept.) at Los Lunas. At Alcalde, the sucrose contents of 'Dagua', 'Honeyjar', 'Lang', 'Li', 'Maya', and 'Sugarcane' increased dramatically from 9 Sept. to 7 Oct. whereas 'Li-2', 'September Late', and 'So' dropped slightly at the beginning then climbed significantly from 24 Sept. to 7 Oct. The sucrose content of 'Shuimen' jujubes remained the same during maturation. On 7 Oct., cultivars ranked from high to low as follows: 'Maya', 'Sugarcane', 'Lang', 'Li', 'Honeyjar', 'Dagua', 'September Late', 'So', 'Li-2', and

'Shuimen' (24 Sept.). At Los Lunas, the sucrose content of '(Y) Lang', 'GA866', 'Lang', 'Li', and 'Sherwood' increased greatly whereas 'Sugarcane' climbed significantly from 25 Aug. to 9 Sept. then dropped slightly from 9 Sept. to 24 Sept. On 24 Sept., cultivars ranked from high to low as follows: 'Sherwood', '(Y) Lang', 'Li', 'Sugarcane', 'Lang', and 'GA866'.

Cultivars containing higher fructose content in fruit tended to have lower sucrose content (Figs. 3 and 4). According to the relative sucrose content compared with glucose and fructose, cultivars were divided into two groups, high-sucrose and low-sucrose.

High-sucrose refers to those cultivars whose fruit contained more sucrose than glucose and fructose (Fig. 5). On the other hand, low-sucrose refers to cultivars with lower sucrose than glucose and fructose (Fig. 5). 'Dagua', 'Honeyjar', 'Lang', 'Li', 'Maya', 'Sugarcane', '(Y) Lang', and 'Sherwood' belong to the high-sucrose group, and 'Li-2', 'September Late', 'Shuimen', 'So', and 'GA866' belong to the low-sucrose group.

Total phenols. Total phenolic content of jujube fruit decreased significantly during maturation (Fig. 6). The average total phenolic content in jujubes of all cultivars on 9 Sept. and 7 Oct. were 42.1 mg GAE/g DW (9 Sept.) and 14.2 mg GAE/g DW (7 Oct.) at Alcalde, and was 28.6 mg GAE/g DW on 9 Sept. at Los Lunas. At Alcalde (7 Oct.), the phenolic contents in jujubes of different cultivars were statistically the same, except for 'September Late', which was lower than that of others. At Los Lunas (9 Sept.), 'Sherwood' had higher phenolic content, and 'Sugarcane' ranked the lowest because of its advanced maturity.

Antioxidants. The DPPH-scavenging efficiency of jujube decreased significantly during fruit maturation, the lower the EC₅₀ value the higher the DPPH-scavenging efficiency (Fig. 7). At Alcalde, the average EC₅₀ of jujubes (including peel and pulp) on 9 Sept. and 7 Oct. were 40.3 and 211.7 µg/mL, respectively. At Los Lunas, the average EC₅₀ on 9 Sept. was 81.6 µg/mL. At Los Lunas, 'Sherwood' had the greatest DPPH-scavenging efficiency whereas 'Sugarcane' ranked the lowest. At Alcalde, 'Li' and 'Li-2' ranked the highest whereas 'Sugarcane', 'Lang', and 'So' ranked the lowest.

Discussion

Jujubes are high in vitamin C content. The vitamin C contents of 46 jujube cultivars at Alcalde, NM, ranged from 225 to 820 mg/100 g FW. This is similar to the results of Bi et al. (1990) with 121 cultivars in China. This is the first jujube cultivar vitamin C profile report in the United States. 'Youzao' would be a good candidate for functional food with its extremely high vitamin C content.

Jujubes have higher vitamin C content than most 'vitamin C rich' fruits and vegetables: guava (230 mg/100 g FW), kiwi (green, 161 mg/100 g FW), kale (130 mg/100 g FW), yellow sweet pepper (183.5 mg/100 g FW), red sweet pepper (127.7 mg/100 g FW), green sweet pepper (80.4 mg/100 g FW), broccoli (89 mg/100 g FW), navel orange (59 mg/100 g FW), Valencia orange (48.5 mg/100 g FW), and red tomato (13.7 mg/100 g FW) (US Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, 2015). The U.S. Department of Health and Human Services and U.S. Department of Agriculture (2015) recommended daily dietary reference intake of vitamin C is 75 mg for adult women and 90 for adult men which is equivalent to 15–40 g fresh jujube fruit (2–5 fruits depending on size) and that is why jujube have been called "natural vitamin C

Table 5. Soluble solids content (%) dynamics of different jujube cultivars in 2014 at both Alcalde and Los Lunas, NM.

Location	Cultivar	No. of trees ^c	9 Sept.	24 Sept.	7 Oct.	SE ^y
Alcalde	Dagua	3	10.7 dC ^a	16.9 gB	28.7 bcA	1.5
	Honeyjar	1	11.0 dB	23.8 cdefA	29.3 abcA	2.5
	Lang	2	11.5 dC	23.7 cdefB	33.7 abA	2.2
	Li	1	12.0 cdC	20.5 cdefgB	31.6 abcA	2.5
	Li-2	1	12.5 cdB	24.6 bcdeA	27.2 abcA	2.5
	Maya	3	14.0 cdC	21.9 cdefB	33.4 aA	1.5
	September Late	3	11.3 dC	18.3 fgB	31.6 abcA	1.5
	Shuimen	2	15.0 bcdA	20.0 defgA	N/A ^w	2.2
	So	3	12.8 dC	18.5 efgB	27.9 cA	1.5
	Sugarcane	3	13.0 cdC	19.6 efgB	31.7 abcA	1.5
Los Lunas	(Y) Lang	3	21.8 aA	25.3 cdA	N/A	1.5
	GA866	1	18.3 abcB	31.1 abA	N/A	2.1
	Lang	2	21.7 aB	31.3 aA	N/A	1.7
	Li	3	19.3 abB	30.5 abA	N/A	1.5
	Sherwood	1	14.3 bcdB	26.9 abcA	N/A	2.1
	Sugarcane	1	23.5 aA	29.5 defgA	N/A	2.5

^aNo. of trees referred to the number of separate trees from which samples were collected for each cultivar. 'Sherwood', 'Li', 'Lang', and '(Y) Lang' at Los Lunas, 'Dagua', 'Maya', 'Sugarcane', 'So', and 'September Late' at Alcalde had three replicates.

^ySE referred to the standard error.

^xThe average soluble solids contents with different lower-case letters within a column are significantly different. The average soluble solids contents with different capital letters within a row are significantly different.

^wCultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

Fig. 2. Glucose content (mg/g FW) dynamics of jujube cultivars. Three extracts were taken for each sample. The average glucose content was reported with the error bar as standard error. Cultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

Fig. 3. Fructose content (mg/g FW) dynamics of jujube cultivars. Three extracts were taken for each sample. The average fructose content was reported with the error bar as standard error. Cultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

pills" and testifies to the Chinese saying: "Eating three red dates daily will keep you young forever" (Liu and Wang, 2009). This vitamin C profile table (Table 1) can serve as a reference for researchers and growers.

Jujube vitamin C content decreased as fruit matured from the creamy stage to the fully mature stage. For the three cultivars (Li, Lang, and Sugarcane) tested at both locations, the high vitamin C content measured at Alcalde was mainly because of its advanced maturity at Los Lunas compared with Alcalde. The high vitamin C of 'Youzao' was partially because of its late maturation leading to sampling at a relatively earlier maturation stage (creamy stage) (Table 1). Considering vitamin C benefit together with fruit flavor, creamy stage for fresh-eating cultivars such as 'Li' would be the best for vitamin C benefit with sweet enough flavor. The creamy stage exhibiting high vitamin C content would be a good time to harvest fruit for processing.

Fruit moisture/soluble solids content and end uses. As fruit matured, moisture content decreased and soluble solids/sugar content greatly increased. Jujube cultivars varied in their moisture/soluble solids content. Location also played an important role in soluble solids content. For the same cultivar at the same date, the soluble solids content at Alcalde was lower than Los Lunas because of its trailing maturation. But the final soluble solids content at maturation was similar because those two locations have similar semiarid weather conditions in the Southwest. 'Honeyjar' at these locations had soluble solids at 29.3% compared with 25.4% as reported in China (Gao et al., 2012b).

Fruit size, texture, and flavor all contribute to the fruit end use, but soluble solids/moisture content is an important factor to determine fruit uses. Jujube cultivars can be classified as fresh eating, drying, processing, multipurpose, and ornamental cultivars. Fresh-eating cultivars tend to have lower soluble solids content, high moisture content, and crispier and juicier texture than drying cultivars. On the other hand, drying cultivars always have higher soluble solids content, less moisture, and dry/woody texture, which are not suitable for fresh eating, but have a high fruit drying percentage. Multipurpose cultivars are in the middle with relatively high soluble solids content and good fruit texture making them suitable for both fresh eating and drying. For the two dominant commercial cultivars, 'Li' is good for fresh eating whereas 'Lang' had the highest soluble solids content at both locations and is more suitable for drying.

Fruit sugar composition. As fruit matured, the total sugar content increased for all cultivars (Figs. 2–5). The pattern for each component depended on the cultivar. The ranges for each sugar component are similar to previous reports in China (Peng et al., 2007). A cultivar's sugar composition also determines its flavor. Besides glucose, fructose, and sucrose, jujube also contains a reasonable amount of rhamnose and a small

Fig. 4. Sucrose content (mg/g FW) dynamics of jujube cultivars. Three extracts were taken for each sample. The average sucrose content was reported with the error bar as standard error. Cultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

Fig. 5. Fruit glucose, fructose, and sucrose contents of jujube cultivars: Maya, Sherwood, Shuimen, and So in 2014 at Alcalde, NM. High-sucrose group: 'Maya' and 'Sherwood'; and low-sucrose group: 'Shuimen' and 'So'.

amount of sorbitol (Gao et al., 2013; Li et al., 2007). The total sugar content of fresh jujube can reach 30% of FW and peaks at late stage of full maturity. On average, jujube has about 2–3 times the sugar content in citrus and peach, 2 times the sugar in pear and apple (Gan et al., 2000).

Recently, diabetes is becoming quite common and sugar toxicity is becoming a concern in nutrition. Goran (2012) mentioned that excess fructose consumption has been linked to gout, hypertension, dyslipidemia, fatty liver disease, diabetes, and obesity. Unlike fructose in high fructose corn syrup, fructose from fruit is encased in fiber-rich flesh, which slows and reduces absorption in the body and metabolism in the liver, serving as a sort of antidote to the negative effects of fructose metabolism (Goran, 2012). Fructose

absorbed into the blood does not tend to stimulate pancreatic insulin production as sucrose does. Compared with other cultivars, 'September Late' (fructose content: 101.6 mg/g FW), 'So' (79.6 mg/g FW), and 'Li-2' (78.4 mg/g FW) contained the highest fructose content in this study. Fructose content in jujubes helps to regulate blood sugar levels because of its function of slowing digestion (Gao et al., 2012b; Wang et al., 2002). Li et al. (2007) reported 42.9% DW of fructose in 'Jianzao'. Cultivars with higher levels of fructose and lower levels of sucrose have the potential to be used as functional food products for those suffering from diabetes. Further research is needed to screen all U.S. jujube cultivars for high fructose content and related food processing potential.

Jujube is rich in antioxidants. The content of total phenols decreased as fruit matured and the content varied by cultivar. Researchers in China also reported similar results (Gao et al., 2012a; Li et al., 2007; Wang et al., 2011). Compared with total phenol content of common fruit species apple (0.68 mg GAE/g DW), banana (0.57 mg GAE/g DW), cherries (1.15 mg GAE/g DW), grape (red) (0.80 mg GAE/g DW), plum (1.02 mg GAE/g DW), and pomegranate (1.47 mg GAE/g DW), jujube fruit is a rich source of phenols. Location, sampling time, and drying method also affect total phenol content. The total phenolic content of 'Honeyjar' jujubes was 9.8 mg GAE/g FW on 7 Oct. at Alcalde, which was higher than the 3.61 mg GAE/g FW reported by Gao et al. (2012b). This might be because of the difference of drying methods employed during sample preparation. Gao et al. (2012b) used sun-drying instead of freeze-drying samples. Gao et al. (2012a) found that the result of total phenolic content when using freeze-drying was higher than that when using sun-drying.

The EC_{50} range is slightly lower compared with the results of Choi et al. (2011), in which the EC_{50} of two jujube cultivars (pulp) were 115.6 and 145.8 $\mu\text{g/mL}$, respectively. Our results are similar to Xue et al. (2009), who reported that 100 $\mu\text{g/mL}$ jujube peel phenolic extract of three cultivars could scavenge about 40% to 50% of the DPPH radicals, and 200 $\mu\text{g/mL}$ jujube pulp was needed to scavenge about 50% of DPPH radicals. Li et al. (2005) reported that the DPPH scavenging efficiency (%) by jujube extract with concentration of 500 $\mu\text{g/mL}$ of five cultivars ranged from 17.8% to 53.4%. Their DPPH scavenging capacity was lower, and consistently, they detected lower levels of total phenolic content (ranged from 5.18 to 8.53 mg GAE/g DW). The difference in phenolic content and antioxidant capacity might be because of location, cultivar, maturity, post-harvest processing, extraction, or other variation.

Jujube fruit phenolic extracts displayed high DPPH-scavenging capacity. The average DPPH-scavenging efficiency (EC_{50}) of jujubes (9 Sept. at Los Lunas and 7 Oct. at Alcalde) ranged from 48.6 to 276.5 $\mu\text{g/mL}$. To compare, the EC_{50} of crabapple harvested 40 d after full bloom reached its lowest point (370 $\mu\text{g/mL}$; lower EC_{50} indicates a higher efficiency) (Chen et al., 2014). The EC_{50} of grape seed extracts from three cultivars of grape ranged from 1.8 to 30 $\mu\text{g/mL}$ (Tounsi et al., 2009). In Alcalde on 9 Sept., the DPPH antioxidant activity had an average EC_{50} value of 40.3 $\mu\text{g/mL}$, including combined jujube peel and pulp. Jujube peel has much higher antioxidant capacity than pulp (Wang et al., 2011). Peel of jujube harvested at the earlier stage of fruit development has high potential to be a good source of antioxidants.

In summary, jujube fruit is a good source of total phenols and antioxidants including vitamin C. Fruit sugar content and composition differ among cultivars. With its rich

Fig. 6. Total phenolic content (mg GAE/g DW) dynamics of jujube cultivars. Three extracts were taken for each sample. The average total phenolic content was reported with the error bar as standard error. Cultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

Fig. 7. DDPH-scavenging efficiency dynamics of jujube cultivars. Three extracts were taken for each sample. The average EC₅₀ was reported with the error bar as standard error. Cultivars at Los Lunas and 'Shuimen' at Alcalde were unavailable on 7 Oct.

nutrient content plus its wide adaption and drought tolerance, jujubes have great potential in the Southwest and are a good candidate for functional foods.

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