Comparison of Drip, Pipe and Surge Spring Root Irrigation for Jujube (Ziziphus jujuba Mill.) Fruit Quality in the Loess Plateau of China

Qing-Han Gao1,2, Jin-Gang Yu1, Chun-Sen Wu1, Zhi-Sheng Wang2, You-Ke Wang4, De-Lan Zhu5, Min Wang1*

1 College of Food Science and Engineering, Northwest A&F University, YangLing, Shaanxi, China, 2 School of Public Health, Ningxia Medical University, Yinchuan, Ningxia, China, 3 Laboratory Animal Center, Ningxia Medical University, Yinchuan, Ningxia, China, 4 College of Resources and Environment, Northwest A&F University, YangLing, Shaanxi, China, 5 College of Water Resources & Architectural Engineering, Northwest A&F University, YangLing, Shaanxi, China

Abstract

Loess Plateau is a typical rain-fed farming region, facing the threat of drought. Irrigation method is among the most important factors affecting jujube quality. This study investigated the response of Ziziphus jujuba Mill. cv. Lizao quality to three different irrigation methods (drip-, pipe- and surge spring root irrigation) combining two water levels (20 m3/hm2 and 120 m3/hm2). The effects of the trials were evaluated by taking into account the physical-chemical characteristics of jujubes and the antioxidant activity. Concomitant to this, the concentration of some taste-related (viz. glucose, fructose, TSS and malic acid) and health-related compounds/parameters (viz. catechin and epicatechin) were generally much greater in jujube fruit treated with drip irrigation (120 m3/hm2). Different irrigation treatments had no significant effects on antioxidant capacity, total phenolics and proanthocyanidins (except for pipe irrigation 20 m3/hm2). The best compromise between quality and irrigation of jujube fruit was achieved with drip irrigation (120 m3/hm2).

Introduction

Fruits are good sources of natural antioxidants and biologically active components, and play an important role in human nutrition in supplying certain constituents in which other food materials are deficient [1]. In particular, jujube fruit is considered as a functional food, due to the epidemiological evidence that a high consumption of jujube, and of all its industrial products, is correlated with a reduced risk of some types of cancers [2,3]. Jujube is recommended for the treatment of some diseases like cardiovascular disease related to the production of radical species resulting from oxidative stress [4]. The contributory factors are due to the presence of vitamins and provitamins, such as ascorbic acid, tocopherols and carotenoids. Additionally, they are rich in a wide variety of phenolics with a high oxygen-radical scavenging and quenching capacity [5,6].

However, the nutrient content of jujube fruit mostly depends on genetic and environmental factors, and the ripening stage [7]. Agricultural practices, such as irrigation, can also influence the nutrient content in fruit [8,9]. Several authors reported that deficit irrigation improved peach fruit quality without affecting tree productivity [10].

Jujube (Ziziphus jujuba Mill.) is one of the most common and economically important fruit tree species in the Loess Plateau area, where drought periods are frequent and water resource is the major factor limiting irrigated agriculture. The loess plateau growers are facing increasing pressure to reduce water use by improving water management. In view of the water crises in the arid area, the loess plateau of China has been tenaciously following the strategy of preserving its water resource and protecting the greenery there. The program reduces water consumption through applying the optional irrigation method. Modern irrigation systems such as surge spring root irrigation and drip irrigation techniques seemed to be promising for use in the arid and semi-arid areas, since water usage is more efficiently, and the small output might prevent a sudden rise in the water table, as compared with other irrigation methods, such as basin or sprinkle irrigation. Thus, it is anticipated that a considerable amount of water will be saved by converting the traditional irrigation systems into the modern methods. Even jujubes would grow and yield well, however, only a part of the entire space between trees is wetted [11]. The aim of the present study was to analyze of the quality changes of jujube fruit produced by different irrigation practices (drip irrigation [DI], pipe irrigation [PI] and surge spring root irrigation SSRI (Figure 1). The effects of the trials were evaluated by taking into account the physical and chemical characteristics of the fruits, as well as the antioxidant activity.
Materials and Methods

Chemicals

Pure standards of succinic acid, malic acid, citric acid, fructose, glucose, sucrose, catechin, epicatechin, cinnamic acid, rutin, quercetin, Folin-Ciocalteau reagent, 2, 2'-azinobis(3-ethylbenzthiazoline-6-sulphonic acid) diammonium salt (ABTS), 2, 2-diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were purchased from Sigma Chemical Co. (St. Louis, MO). Other reagents were of analytical grade.

Plant Material and Experimental Design

Site description. Field experiments were conducted in a jujube orchard at Yulin Agro-Eco Experimental Station, which is a research center of Northwest A&F University, and the field studies did not involve endangered or protected species. The Agro-Eco Experimental Station is located in Shaanxi Province in the North China (110°17′E, 37°36′N; average elevation, 1049 m). This area has a semi-arid continental climate (based on data for 1956–2006): with mean annual precipitation of 505 mm; a mean annual temperature of 8.6 °C, with mean monthly temperatures ranging from −6.5 °C in January to 22.8 °C in July; 2720 h of sunshine on average each year [12]. The whole area of the orchard is covered by loess (Inceptisols, USDA) with silt loam texture, which developed from wind-deposited loess parent material [13].

Treatments. The experimental design was randomized complete block with three replicates per treatment. Each treatment contained four rows with five trees in each row. The seven treatments were the control treatment (CK) involved no irrigation over the entire crop season, DI, PI and SSRI. Each irrigation treatment was applied with two levels of water (20 m³/hm² or 120 m³/hm²) per tree. Each irrigation treatment separated from each other with at least a row of none experimental trees.

All of the treatments were managed identically, and typical pruning and pest and disease control were applied to the trees. Weed control was performed manually. The jujube trees were irrigated for two times (applied at blossoming and bearing fruits stage on 21/5/2010 and 22/7/2010 fruit spreading growth stage, respectively) over the entire crop season.

Samples. A total of 1 kg of jujube fruits picked from eight year old jujube trees at their white ripening stage was subjected to each irrigation treatment with three replicates.

Quality Indexes

The moisture content of jujube fruits was determined by an oven-drying method at 70 °C until constant weight was achieved. The moisture content of the fruit was calculated as a percentage loss of the fruit weight. The content of total soluble solids (TSS) in the juice was measured with a refractometer (Atago Co. Ltd., Tokyo, Japan) and titratable acidity (TA) was determined by titration with NaOH and phenolphthalein indicator. Ascorbic acid content was determined using the 2, 6-dichlorophenolindophenol titration method [14].

Sugar and Organic Acid Determination

For the extractions of sugar and organic acid profiles, 5 g of fruit was extracted with 50 mL of purified water by ultrasonic bath for 20 min. The supernatant was separated and the residue was re-extracted by repeating the above steps under the same conditions. The two filtrates were combined, and then the solvent was evaporated under vacuum at 65 °C for sugars and 55 °C for organic acids. All extracts were stored at −20 °C in the dark until use.
Samples were filtered through a 0.45 μm membrane filter (Iwaki Glass) before HPLC analysis. The concentrations of soluble sugars (glucose, fructose and sucrose) in the fruit were determined by a Waters HPLC system with a refractive index detector (Waters corp., USA) [8]. The HPLC analysis was performed using an Inertsil NH2 column (4.6 mm×250 mm, 5 μm) (GL Sciences, Japan). The mobile phase was acetonitrile: water (80:20), with a flow rate of 1.4 mL/min. The column was operated at 35°C. Sample injection volume was 10 μL.

The organic acid concentration was determined by Waters HPLC system (Waters corp., USA) based on the method described by Gao et al. [6], using an Atlantis T3 column (4.6×150 mm, 3 μm) (Waters corp., USA), coupled with a 2487 UV-Vis wavelength detector set at 210 nm. The mobile phase was 0.5% NH4H2PO4, adjusted to pH 2.6 with ortho-phosphoric acid. The flow rate was 0.8 mL/min.

**Phenolic Compounds Determination**

20 g of jujubes were blended for 3 min in 200 mL of 80% methanol using a Waring blender. The mixture was then homogenized in a high-speed homogenizer for 3 min and then placed in an ultrasonic bath and sonicated for 20 min. Samples were then filtered through a 0.45 μm microporous membrane. The filtrate was collected, and the solid was extracted two more times with the same volume of fresh solvent. The two filtrates were combined and filtered in a vacuum and rinsed with 100% methanol, and then the solvent was evaporated using a rotary evaporator at 45°C until the weight of the evaporated filtrate was <10% of the weight of the original filtrate. The final evaporated filtrate were collected carefully into a volumetric flask and standardized to a final volume of 25 mL with methanol. All extracts were stored at −20°C in the dark until use.

The extracts were analyzed using an analytical HPLC unit (Waters), with a Dikma Diamonsil C18 column (4.6, 150 mm, 5 μm) (Dikma Technologies Inc., USA). The solvent system used was methanol (A) and ultrapure water (pH 2.6) (B). Elution was performed at a flow rate of 0.8 mL/min and the gradient was as follows: 15% A at 0 min, 25% A at 15–25 min, 75% A at 65 min, 15% A at 70 min. Detection was achieved with a binary pump UV-Vis detector (2487). The compounds in each sample were identified by comparing their retention times with the standards and quantified of catechin, epicatechin, rutin, cinnamic acid and quercetin at 280 nm.

**Total Phenolics Content (TPC) Determination**

For total phenolics determination, the samples obtained for individual phenolic compounds analysis were used. TPC of jujube fruit extracts was determined using the Folin–Ciocalteu reagent [15]. The reaction mixture contained 125 μL of extract, 300 μL of deionized water and 125 μL of Folin–Ciocalteu reagent. The mixture was allowed to react for 6 min then 1.25 mL of Na2CO3 (7%) solution and 1 mL distilled water were added and mixed well. The solution was incubated at room temperature in the dark for 1.5 h. The absorbance was measured at 760 nm using a spectrophotometer. Gallic acid was used as a standard and results were calculated as milligram of gallic acid equivalents (GAE) per 100 gram of extract.

**Proanthocyanidin Determination**

For proanthocyanidin determination, the samples obtained for total phenolics analysis were used. Proanthocyanidin content was determined in sealed tubes, 0.1 mL sample was added to a mixture of 0.9 mL MeOH, 6 mL n-BuOH/concentrated HCl (95:5 v/v) and 0.2 mL of a 2% NH4Fe(SO4)2·12 H2O solution in 2 M HCl. Absorbance was read at 530 nm before and after heating for 40 min at 95.0±2.2°C [16].

**Antioxidant Activity Determination**

The tests used to determine the antioxidative capacity of the fruit were the ABTS and DPPH radical scavenging assay. The antioxidant activity was expressed as mmol Trolox eq./100 g FW.

ABTS radical cation scavenging assay was carried out following a modified method of Iqbal et al. [17]. ABTS radical cation was prepared by passing a ABTS aqueous solution through the oxidizing reagent, manganese dioxide, on Fisher Brand P8 filter paper. Excess manganese dioxide was removed from the filtrate by passing the solution through a 0.2 mm Fisher Brand membrane. The extracts were diluted with phosphate buffered saline (PBS, pH 7.4), to an absorbance of about 0.700 (±0.020) at 734 nm. 200 μL of each of the extracts was added to 3 mL of diluted ABTS+ solution and the absorbance reading was taken 1 min after the initial mixing at room temperature. PBS was used as the blank.

DPPH radical scavenging capacity was estimated according to He et al. with slight modification [18]. One milliliter of diluted extract was mixed with 1 mL of DPPH solution, the mixture was kept in the dark for 30 min and the absorbance at 517 nm was measured.

**Statistical Analysis**

The data were analyzed using SPSS software (PASWStatistics18.0). All results are expressed as the mean ± standard deviation (SD) of three replicates. Two-way analysis of variance (ANOVA) was used to evaluate differences between treatments. All of the statistical differences were carried out at a significance level of α = 0.05.

**Results and Discussion**

**Quality Indexes**

The quality characteristics of jujubes including fruit weight, moisture content, TSS, TA and ascorbic acid of jujubes cultivated under SSRI, PI and DI treatments at two water levels are shown in Table 1. DI 120 was positively influenced the quality characteristics of jujube fruits when compared to other irrigation treatments. Fresh fruit weight is an important external quality attribute of jujube fruit and is mainly determined by the cultivar. However, within the same cultivar, the fresh weight is also affected by the irrigation treatment to some extent [19]. Fresh jujube fruit weight and moisture content of DI 120 generally had higher values than those of SSRI and PI. The values of fruit weight and moisture content increased with increasing applied water level (Table 1), meaning that well-irrigated trees increased the size of jujube fruit. In addition, fruit weight increases in the drip-irrigation could be attributed in part to increased nutrient availability under irrigation, as indicated by Liu et al [20]. A previous study has indicated that fresh weight of full irrigation fruits was higher in low crop load than in commercial crop load because of the higher water content [21].

In jujube, TSS at the ripe stage is the most important factor for consumer acceptance regardless of acidity. Analysis of fruit quality data indicated a significant increase in fruit TSS content in DI (20 and 120 m3/hm2) and PI (120 m3/hm2) treatments. Jujube fruits under the treatments of DI (120 m3/hm2) and PI (120 m3/hm2) reached higher values of juice TSS and TA than control fruits, and they could have improved the flavour of the fruit juice and therefore the commercial quality and consumer acceptance. The
Effect of Irrigation on Jujube Fruit Quality

Table 1. Moisture, fruit weight, total soluble solids (TSS) and titratable acidity (TA) of jujube fruit, in relation to the different irrigation practices.

| Compounds      | Control | SSRI (m³/hm²) | DI (m³/hm²) | PI (m³/hm²) |
|----------------|---------|--------------|-------------|-------------|
|                |         | 20           | 120         | 20          | 120         | 20          | 120         |
| Moisture (%)   | 19.2±0.1 cd | 17.3±0.1e d  | 18.5±0.3 d  | 20.1±0.2 bc | 21.3±0.2 a  | 19.2±0.1 cd | 20.5±0.3 ab |
| Weight (g)     | 16.7±0.4 e | 22.9±1.5 d   | 26.7±1.0 c  | 23.4±0.7 d  | 31.8±1.3 a  | 25.7±1.1 c  | 28.9±0.2 b  |
| TSS (%)        | 15.3±0.2 c | 12.9±0.1 d e | 14.3±0.2 d  | 16.1±0.4 b  | 17.1±0.1 a  | 15.0±0.1 c  | 17.2±0.1 a  |
| TA (%)         | 0.07±0.01 bc | 0.07±0.01 c  | 0.11±0.01 a | 0.06±0.01 c | 0.10±0.02 ab | 0.10±0.00 ab | 0.13±0.03 a |

Data are mean ± standard deviation for n = 3. Means in the same line with different letter are significantly different (P<0.05).

Table 2. Effect of different irrigation methods on ascorbic acid (mg/100 g FW), total phenolics (mg GAE/100 g FW), proanthocyanidins (mg GSPE eq./100 g FW), DPPH (%) and ABTS (mmol trolox eq/100 g FW) in jujube fruits.

| Compounds                  | Control | SSRI (m³/hm²) | DI (m³/hm²) | PI (m³/hm²) |
|----------------------------|---------|--------------|-------------|-------------|
|                            |         | 20           | 120         | 20          | 120         | 20          | 120         |
| Ascorbic acid              | 208.9±15.1 abc | 176.0±6.9 d  | 225.0±15.9 a | 203.1±9.1 abc | 220.2±26.9 a | 188.9±12.0 cd | 194.8±7.9 bcd |
| Total phenolics            | 396.2±35.9 b | 398.1±27.4 b | 430.5±36.1 ab | 438.0±10.6 ab | 458.2±17.7 a | 395.2±6.8 b  | 440.3±11.1 ab |
| Proanthocyanidins          | 434.8±10.4 b | 491.0±35.1 a | 479.3±52.4 ab | 486.1±20.4 a | 482.6±53.4 a | 386.0±24.2 c | 457.1±17.4 ab |
| Antioxidant activity       |         |              |             |             |             |             |             |
| DPPH                      | 17.0±5.4 c | 25.5±5.0 ab  | 28.5±5.5 a  | 19.2±2.8 bc | 23.4±2.2 ab | 24.0±0.6 ab  | 28.9±3.9 a  |
| ABTS                      | 3.4±0.2 c | 4.4±0.2 abc  | 5.4±1.3 a   | 3.9±0.3 bc  | 3.8±0.4 bc  | 4.3±0.8 abc  | 5.1±0.5 ab  |

Data are mean ± standard deviation for n = 3. Means in the same line with different letter are significantly different (P<0.05).
respectively. Similarly, all the 120 m$^3$/hm$^2$ treatments resulted in irrigation in comparison 2.6- to 1.6-fold increase in SSRI and DI.

Sugar, Organic Acid, Phenolic Compositions

Sugars are the major component of TSS apart from organic acids, amino acids and soluble pectins. Sweetness which is related to the sugar content of the fruit is an overriding factor in the eating quality of jujubes. Though the consumer preference varied but in general, consumer prefers fruit with high sugar and low acid levels [35]. Apart from the genetics of a cultivar, fruit quality is influenced by cultural practices such as nutrition, irrigation and harvesting [35,36].

Sucrose was the main soluble sugar found in jujubes whereas fructose and glucose were the main reducing sugars (Table 3). Fructose is present in the largest amounts for jujube. Sugars were differentially affected by irrigation practices. Fructose and glucose were both much higher in fruit from plants treated with DI 120 as compared to other treatments. There was a significant interaction between irrigation and fruit sucrose, where the concentration was highest in jujube fruit from plants treated with PI 120. DI 120 treatment resulted in highest levels of glucose (2431.7 mg/100 g FW) in jujube fruit. A 5.6-fold increase was observed in glucose levels in DI in comparison to the control. There was a 3.1-fold increase in glucose (2431.7 mg/100 g FW) in jujube fruit. A 4.3-fold increase was observed in succinic acid levels from 17.4 mg/100 g FW (control) to 74.7 mg/100 g FW (SSRI 120) in comparison to 3.9-fold increase in DI 120 and PI 120, respectively. A 3-fold increase was observed in malic acid levels in jujube fruits irrigated with 120 m$^3$/hm$^2$ water. The PI 120 treatment resulted in highest succinic acid level (123.1 mg/100 g FW) in jujube fruit. A 4.3-fold increase was observed in succinic acid levels from 17.4 mg/100 g FW (control) to 74.6 mg/100 g FW (SSRI 120) in comparison to 3.9-fold increase in DI 120. Sánchez-Bel et al. [37] reported that the irrigation produced almonds with a higher content in oxalic, citric and malic acids than the nonirrigated almond trees. Souza et al. [38] observed in grapes an increase of these same organic acids in grapes under irrigation. The effect of water stress during the herbaceous period of berry development on acidity has been earlier reported for other varieties or conditions [35,36].

Changes in the phenolic compounds of jujubes differed according to the irrigation treatments since fruits are collected in the same date, and cultivated under the same crop conditions (Table 3). Water availability can considerably affect plant phenolic metabolism and composition in fruit [39]. Flavonoids (including epicatechin, catechin, rutin and quercetin) are commonly classified as “environmental compounds” because they are often produced in direct response to environmental conditions [40]. For example, it has been reported that the flavonoids content is dependent on UV-B irradiation, water stress and CO$_2$ levels [41,42]. The obtained results show that water management may influence the individual phenolic content of jujube fruit. In the present work we report that epicatechin, catechin, rutin, quercetin and cinnamic acid were detected in jujube samples. Similar HPLC patterns of

| Compounds | Control | SSRI (m$^3$/hm$^2$) | DI (m$^3$/hm$^2$) | PI (m$^3$/hm$^2$) |
|-----------|---------|---------------------|-------------------|------------------|
|           | 20      | 120                 | 20                | 120              |
| Sugars (mg/100 g FW) |         |                     |                   |                  |
| Sucrose   | nd      | 308.4±24.9           | 262.8±19.2        | 418.0±27.9       |
| Glucose   | 436.3±16.4 | 556.0±19.6           | 1509.1±95.0       | 1947±207.7       |
| Fructose  | 694.5±30.1 | 574.9±26.3           | 1836±201.9        | 2150.8±178.3     |
| Organic acids (mg/100 g FW) |         |                     |                   |                  |
| Citric acid | 34.0±2.0 | 66.2±4.5            | 135.7±5.0         | 197.7±32.6       |
| Malic acid | 98.2±5.8 | 117.9±6.3           | 348.6±36.5 ab     | 320.5±23.5       |
| Succinic acid | 17.4±0.7 | 46.2±5.5 cd         | 53.8±6.5          | 123.1±6.5       |
| Phenolic compounds |         |                     |                   |                  |
| Catechin (mg/100 g FW) | 5.64±0.58 | 14.9±0.8           | 15.4±0.7         | 15.8±0.4 ab      |
| Epicatechin (mg/100 g FW) | 21.2±0.8 | 32.2±1.1 bc         | 30.4±1.1         | 37.1±4.5 ab      |
| Rutin (mg/100 g FW) | 1.44±0.05 a | 1.17±0.05         | 0.96±0.03         | 1.23±0.06       |
| Quercetin (mg/100 g FW) | nd | 560.3±3.5            | 20.7±2.4          | nd                |
| Cinnamic acid (mg/100 g FW) | nd | 10.3±0.4            | 9.9±0.5 bc        | nd                |

Data are mean ± standard deviation for n = 3. Means in the same line with different letter are significantly different (P<0.05).

Abbreviations: nd, not detected.

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epicatechin, catechin, rutin were observed for all irrigated samples however, their contents differed depending on the irrigation treatments. All the irrigation treatments increased the content of epicatechin and catechin compared to control. The results agreed with Sanchez-Rodriguez et al. [40], who reported that Z. × Z. and J. jujubae had the highest values of some individual phenolic compounds under well-watered conditions. The content of rutin reduced for all the irrigated jujube samples compared to control. Epicatechin and catechin are the main antioxidants present in the jujube fruits under different irrigation practices. For irrigated samples, jujube trees with DI 120 had higher contents of epicatechin, catechin and rutin (37.5, 16.3 and 1.25 mg/100 g FW, respectively) whereas SSRI 20, showed a significantly higher content of querectin (56.0 μg/100 g FW). A small number of cinamic acid was detected in SSRI and PI treatments.

The levels of water did not cause significantly change of epicatechin and catechin for SSRI and PI, while the higher levels of water for DI enhanced the contents of epicatechin and catechin. The content of querectin for SSRI 20 was about 2.7-fold compared to that of SSRI 120.

Different hypothesis have been developed to explain the differences found in the phenolic compounds of plants under irrigation: the different water content of the fruits that could imply a different solubilization of phenolices which are more soluble in water and a different effectiveness in the release of phenolic compounds during crushing and malaxation linked to polysaccharides of the cell wall, and the water stress suffered by the trees that could imply a greater synthesis of phenolic compounds in the fruit [8].

From the results obtained in this trial, differences in the content of phenolic compounds in jujubes may be the consequence of the water content of the fruits, since phenolics content in jujubes from the irrigation treatments. All the irrigation treatments increased the content of phenolic compounds in jujubes may be the consequence of the water stress suffered by the trees [8].

From the results obtained in this trial, differences in the content of phenolic compounds in jujubes may be the consequence of the water content of the fruits, since phenolics content in jujubes from control treatment were significantly different from that in jujubes from the irrigation treatments. In peach trees, it has been reported that soil moisture stress may be related to the increase in phenolics from the irrigation treatments. All the irrigation treatments increased the contents of epicatechin and catechin compared to control. The results agreed with Sanchez-Rodriguez et al. [40], who reported that Z. × Z. and J. jujubae had the highest values of some individual phenolic compounds under well-watered conditions.

Conclusions
The data resulting from this research work indicate that jujube fruit had a positive response to irrigation practices but this response differed according to the amount of water applied. TPC, ascorbic acid content and antioxidant activity did not show significant variability with irrigation treatments while different irrigation regimes applied affected quality indexes and the composition of sugar, organic acid and phenolics. It is important for growers to understand the balance between enhancing phytochemical content by applied the appropriate irrigation and maintaining good quality of the product. The loess plateau areas also calls for the establishment of a suitable compromise between quality of jujube fruits and water consumption. Then, the selection of an optimal irrigation treatment of DI 120 for jujube cultivar in loess plateau is full of importance. SSRI as a promising technique in the arid and semi-arid areas supplies jujubes with water and nutrients at frequent intervals, permits minimal evaporation in comparison with PI and permits slow rates of water application that help maintain a stable water table. More work is necessary to confirm these data over an even longer term, to determine optimum water levels and timing for best fruit quality, and to further improve methods such as SSRI for monitoring and maintaining water consumption.

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Author Contributions
Conceived and designed the experiments: QHG JGY CSW. Analyzed the data: QHG CSW ZSW. Performed the experiments: QHG JGY MW. Contributed reagents/materials/analysis tools: VKW DLZ. Wrote the paper: QHG.

References
1. Ikram EHK, Eng KH, Jalih AMM, Ismail A, Idris S, et al. (2009) Antioxidant capacity and total phenolic content of Malaysian underutilized fruits. J Food Compos Anal 22: 388–393.
2. Plastina P, Bonolfiglio D, Vizza D, Fazio A, Rovito D, et al. (2012) Identification of bioactive constituents of Ziziphus jujub fruit extracts exerting antiproliferative and apoptotic effects in human breast cancer cells. J Ethnopharmacol 140: 325–332.
3. Gao QH, Wu CS and Wang M (2013) The jujube (Ziziphus jujuba Mill.) fruit: a review of current knowledge of fruit composition and health benefits. J Agric Food Chem 61: 3551–3563.
4. Zhang H, Jiang L, Ye S, Ye Y, Ren F (2010) Systematic evaluation of antioxidant capacities of the ethanolic extract of different tissues of jujube (Ziziphus jujuba Mill.) from China. Food Chem Toxicol 48: 1461–1465.
5. Li JW, Ding SD, Ding XL (2005) Comparison of antioxidant capacities of extracts from five cultivars of Chinese jujube. Process Biochem 40: 3607–3613.
6. Gao QH, Wu CS, Yu JG, Wang M, Ma YJ, et al. (2012) Textural characteristic, antioxidant activity, sugar, organic acid, and phenolic profiles of 10 promising jujube (Ziziphus jujuba Mill.) selections. J Food Sci 77: C1218–1225.
7. Gao QH, Wu PT, Liu JR, Wu CS, Parry JW, et al. (2011) Physico-chemical properties and antioxidant capacity of different jujube (Ziziphus jujuba Mill.) cultivars grown in loess plateau of China. Sci Hortic 160: 67–72.
8. Navarro JM, Pérez-Pérez JM, Romero P, Botia P (2010) Analysis of the changes in quality in mandarin fruit, produced by deficit irrigation treatments. Food Chem 119: 159–168.
9. Piklomi ED, Nanos GD, Gil MI (2010) Two-Season Study of the Influence of Regulated Deficit Irrigation and Reflective Mulch on Individual and Total Phenolic Compounds of Nectarines at Harvest and during Storage. J Agric Food Chem 58: 11783–11789.
10. Girone J, Gelly M, Mata M, Arbonés A, Rufat J, et al. (2005) Peach tree response to single and combined deficit irrigation regimes in deep soils. Agr Water Manage 72: 97–108.
11. Hutton RJ, Lowery BR (2011) A partial root zone drying irrigation strategy for citrus: Effects on water use efficiency and fruit characteristics. Agr Water Manage 98: 1405–1406.
12. Gao XP, Wu PT, Zhao XN, Shi YG, Wang JW (2011) Estimating spatial mean soil water contents of drip-irrigated jujube orchards using temporal stability. Agr Water Manage 108: 66–73.
13. Zhu XM, Li YS, Peng XL, Zhang SG (1983) Soils of the loess region in China. Geoderma 29: 237–255.
14. AOAC. Official Methods of Analysis, 15th ed.; George Banta (1996) Washington, DC: Association of Official Analytical Chemists.
15. Kumar MSV, Datta R, Prasad D, Mira K (2011) Subcritical water extraction of antioxidant compounds from Seabuckthorn (Hippophae rhamnoides) leaves for the comparative evaluation of antioxidant activity. Food Chem 127: 1309–1316.
16. Froehlicher T, Hennebelle T, Martin-Nizard F, Glérénerick P, Hélbert JL, et al. (2009) Phenolic profiles and antioxidative effects of hawthorn cell suspensions, fresh fruits, and medicinal dried parts. Food Chem 115: 897–903.
17. Ishqal S, Bhangar MI, Anwar F (2005) Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. Food Chem 93: 265–272.
18. He L, Xu H, Liu X, He W, Yuan F, et al. (2010) Identification of phenolic compounds from pomegranate (Punica granatum L.) seed residues and investigation into their antioxidant capacities by HPLC–ABTS + assay. Food Res Int 44: 1161–1167.
19. Wang F, Kang S, Du T, Li F, Qiu R (2011) Determination of comprehensive quality index for tomato and its response to different irrigation treatments. Agr Water Manage 98: 1228–1238.
20. Liu K, Zhang TQ, Tan CS, Astatkie T (2011) Responses of fruit yield and quality of processing tomato to drip-irrigation and fertilizers phosphorus and potassium. Agron J 103: 1339–1345.
21. Burundi B, Allende A, Nicolás E, Alarcón JJ, Gil MI (2008) Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J Agric Food Chem 56: 3601–3608.
22. Malash N, Flowers TJ, Ragab R (2005) Effect of irrigation systems and water management practices using saline and non-saline water on tomato production. Agr Water Manage 78: 25–38.

23. Amer KH (2011) Effect of irrigation method and quantity on squash yield and quality. Agr Water Manage 98: 1197–1206.

24. Favati F, Lovelli S, Galgano F, Miccolis V, Di Tommaso T, et al. (2009) Processing tomato quality as affected by irrigation scheduling. Sci. Hortic 122: 562–571.

25. Zong L, Tedeschi A, Xue X, Wang T, Menenti M, et al. (2011) Effect of different irrigation water salinities on some yield and quality components of two yield-grown Cucurbit species. Turk J Agric For 35: 297–307.

26. Mahajan G, Singh KG (2006) Response of Greenhouse tomato to irrigation and fertigation. Agr Water Manage 84: 202–206.

27. Pérez-Pastor A, Ruiz-Sánchez MC, Martínez JA, Nortes PA, Artés F, et al. (2007) Effect of deficit irrigation on apricot fruit quality at harvest and during storage. J Sci Food Agr 87: 2409–2415.

28. Gelly M, Recasens I, Girona J, Mata M, Arbones A, et al. (2004) Effects of stage II and postharvest deficit irrigation on peach quality during maturation and after cold storage. J Sci Food Agr 84: 561–568.

29. Mitchell JP, Shuman C, Grattan SR (1991) Developmental changes in tomato fruit composition in response to water deficit and salinity. Physiol Plantarum 83: 177–185.

30. Castellarnau SD, Matthews MA, Gaspero GD, Gambetta GA (2007) Water deficits accelerate ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta 227: 101–112.

31. Jordan MJ, Martinez RM, Martinez C, Motño I, Sotomayor JA (2009) Polyphenolic extract and essential oil quality of Thymus zygis spp. gracilis shrubs cultivated under different watering levels. J Agric Food Chem 29: 145–153.

32. Kong KW, Chew LY, Prasad KN, Lau CY, Ismail A, et al. (2011) Nutritional constituents and antioxidant properties of indigenous kembayau (Dacryodes rostrata (Blume) H. J. Lam) fruits. Food Res Int 44: 2332–2338.

33. Tovar MJ, Romero MP, Giroma J, Mosty M:J (2002) L-Phenylalanine ammonia lyase activity and concentration of phenolics in developing olive (Olea europaea L. cv. Arbequina) fruit grown under different irrigation regimes. J Sci Food Agr 82: 892–896.

34. Pernice R, Parisi M, Giordano I, Pentangelo A, Graziani G, et al. (2010) Antioxidant profile of small tomato fruits: Effect of irrigation and industrial process. Sci Hortic 126: 156–163.

35. Thakur A, Singh Z (2012) Responses of ‘Spring Bright’ and ‘Summer Bright’ nectarines to deficit irrigation: Fruit growth and concentration of sugars and organic acids. Sci Hortic 135: 112–119.

36. Santesteban LG, Miranda C, Royo JB (2011) Regulated deficit irrigation effects on growth, yield, grape quality and individual anthocyanin composition in Vitis vinifera L. cv. ‘Tempranillo’. Agr Water Manage 98: 1171–1179.

37. Sánchez-Bel P, Eges I, Martínez-Madrid MC, Flores B, Romojaro F (2008) Influence of irrigation and organic/inorganic fertilization on chemical quality of almond (Prunus amygdalus cv. Guarra). J Sci Food Agr 86: 10056–10062.

38. Souza CR, Marocco JP, Dos Santos TP, Rodrigues ML, Lopes CM, et al. (2005) Grape berry metabolism in field-grown grapevines exposed to different irrigation strategies. Vitis 44: 103–109.

39. Tomas-Barberan FA, Espin JC (2001) Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. J Sci Food Agr 81: 853–876.

40. Sanchez-Rodriguez E, Ruiz JM, Ferreres F, Moreno DA (2012) Phenolic profiles of cherry tomatoes as influenced by hydric stress and rootstock technique. Food Chem 134: 773–782.

41. Bandurska H, Pietrowska-Borek M, Cieslak M (2011) Response of barley seedlings to water deficit and enhanced UV-B irradiation acting alone and in combination. Acta Physiol Plant 34: 161–171.

42. Caldwell CR, Britz SJ, Mirecki RM (2005) Effect of temperature, elevated carbon dioxide, and drought during seed development on the isoflavone content of dwarf soybean [Glycine max (L.) Merrill] grown in controlled environments. J Agric Food Chem 53: 1125–1129.

43. Kubota N, Kudo S (1992) Effects of soil moisture tension on phenolic contents and astringency in peach fruits. J Jpn Soc Hortic Sci 61: 31–37.