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The Effects of Low-Input (Wild and Organic Farming) Conditions on the Nutritional Profile of *Ziziphus jujuba* Mill. Fruits from the Valencian Mediterranean

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Abstract: Jujube fruit (*Ziziphus jujuba* Mill.) has been a food source since ancient times. In Spain, it is considered a marginal crop, and jujube fruits are of low economic importance. Its consumption is bound to local marketplaces. However, jujube is a good alternative crop due to its climatic adaptation and low-input conditions. We aimed to evaluate the morphological, physicochemical, and bioactive compounds of jujube fruits grown under low-input conditions (wild and organic farming) in the Mediterranean basin, specifically in Marjal de los Moros, Valencia, Spain. The organic system produces higher protein, fiber, ash, and carbohydrate concentrations from small-caliber fruit cultivars. Potassium and phosphorus are the major mineral elements in jujube. The fruits' total polyphenols range from 480.83 to 630.81 mg EGA·100 g^{-1} fw in organic conditions and 520.71 mg EGA·100 g^{-1} fw in wild conditions. Low-input conditions influence the production of glucose (sweet fruits) and bioactive compounds, as well as mineral concentrations. A strong relationship exists between vitamin C levels and the potassium concentration. Jujube fruits are classified as "vitamin C-rich". A 20 g serving of fruit can provide the regular vitamin C requirements of an adult person. The environmental and nutritional opportunities offered by jujubes are in line with different SDGs.

Keywords: vitamin C; undervalued fruits; low-input farming; jujube; total polyphenols

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1. Introduction

Humans use a wide range of fruits from the plant world for different purposes, the most important of which are food and health maintenance. They are rich in vitamins and minerals, promote a healthy state, or contain active ingredients capable of preventing and treating diseases [1]. Fruits' reputation focuses solely on being vital sources of minerals and vitamins, as well as fiber and antioxidants. These compounds provide great health benefits; therefore, the FAO [2] recommends a minimum consumption of 400 g of vegetables and fruits daily to thwart non-communicable diseases, malnutrition, and micronutrient deficiencies [3,4].

The genus *Ziziphus* comprises 86 species (up to 170, according to some authors) [5–8] cultivated in the driest areas of both hemispheres. Taxonomically, it belongs to the Rhamnaceae family. *Ziziphus jujuba* is generally known as jujube, red date, or Chinese date, with many synonyms worldwide. This species and its large variety of cultivars are found on five continents, which implies its use as a food source for centuries [9]. China is the main exporter of jujube, with an important cultivation and production area [10]. Around 90% of jujube is produced in China, and its demand for pharmacological applications and food is increasing [11]. These fruit trees also play a key environmental role, protecting against sandstorms and conserving water and soil in sparsely vegetated areas [12]. Some countries have a growing interest in producing this species for its beneficial health properties and ease of cultivation under adverse soil and climatic conditions [13].

Two species have been identified in the flora of the Iberian Peninsula: the cultivated jujube (*Z. jujuba* Mill.) and the wild jujube (*Z. lotus*), which is a native species of the Almeria and Murcia provinces [14,15]. Although all cultivars are edible, their quality differs due to various factors such as geoclimatic conditions, cultivation methods, cultivars, maturity stages, processing, and storage conditions [16,17]. The main classification corresponds to the size, shape, and sweetness of the fruit [18].

Jujube trees are on the list of species grown in the Generalife orchards (La Alhambra, Granada, Spain) [19]. Currently, *Z. jujuba* Mill. is a marginal and undervalued crop in Spain mainly cultivated for self-consumption and ornamental purposes. It is a fruit species that can be cultivated in waterless and semi-arid zones due to its ease of adaptation, low water requirements, and high tolerance to salinity [8]. Therefore, *Z. jujuba* Mill. is an important fruit species in Southeastern Spain, where it is grown sporadically in home gardens as a food and economic alternative to other species [20]. In September, it is sometimes possible to find jujubes in the traditional markets, where they are highly appreciated by connoisseurs for their sensory characteristics.

From one perspective, the temporal consumption of unappreciated species minimizes the inputs used to grow them since they effortlessly acclimate to ecological situations. On the other hand, cultivating various foods with time-based alternatives during the year has been proposed as a source of healthy diets that can prevent chronic degenerative diseases [17]. The expanding requirement to eat wholesome foods has brought attention to the use and exploration of undervalued edible fruit species which, as local products, could decrease the carbon footprint and reduce the burden of non-communicable diseases associated with diet. It can also help achieve some of the Sustainable Development Goals.

Among their many properties, jujube fruits have been shown to have antioxidant activity [21] and antifungal, antibacterial [22], anti-inflammatory [23], and immunostimulatory properties [24]. At present, very few plant species are used by humans on a large scale, either directly for food or for other purposes, such as industrial or medicinal purposes.

Driven by the desire to provide useful added value to healthy dietary intake requirements, research was conducted on the morphological characterization, nutritional composition, and health-benefitting chemical constituents of three Spanish jujube varieties. These fruits were obtained from low-input crops. Against this backdrop, the undervalued fruits of *Z. jujuba* Mill. in Spain present fluctuations in their nutritional goodness and biologically active substances depending on the fruit variety and its growing environment. In this study, we assessed differences in the composition of jujube fruits from low-input environments by studying wild and organic farming methods in the Valencian Mediterranean. In this respect, we proposed proximal and mineral studies for quantifying bioactive substances, along with other biochemical and morphological constituents.

2. Materials and Methods

2.1. Vegetable Material

Ziziphus jujuba Mill. (jujubes) is a tree native to the East. In the Iberian Peninsula, it is marginally and locally cultivated apart from being found in the wild. It is resistant to low temperatures [25]. Fruit ripening occurs between late August, September, and early October. In general, jujube trees can tolerate high temperatures (49–50 °C) during dormancy, but while flowering and fruiting, the temperature should be around 30 °C and <35 °C. The optimal relative humidity values for fruiting range between 25 and 45%. Jujube trees thrive with annual rainfall between 300 and 400 mm, and water supply is most appropriate during the sprouting stage, rather than during the flowering stage.

The fruit is an oval drupe, with a single hard oval stone of variable size, which determines it heterogeneity. The color of the exocarp varies from bright green to dark hazel at maturity; the flesh is white or yellowish-white, fragrant, and sugary in flavor. Shortly after full maturity, the fruit begins to soften and shrivel [26].

For the present study, we selected three non-typified jujube cultivars (*Z. jujuba* Mill.). The fruits were harvested from trees in Marjal de los Moros, Valencia, Spain. The area is located 39°45′13″ West, with SCI code ES0000148 [27]. According to Papadakis' classification, this area has a Mediterranean climate. The annual average temperature is 17.8 °C, with mild temperatures in winter (mean 11.2 °C in January) and dry and hot summers (25.7 °C in August). It has a scarce annual precipitation of 400 mm, mostly falling in spring (March) and autumn (November).

Two of the jujube fruit samples were grown under homogeneous organic conditions at the Garden of Mediterranean Landscapes (Environmental Education Center), which includes a collection of jujube trees that differ in fruit size. Under organic conditions, biannual contributions of 15–20 tons of sheep manure were distributed per hectare. Half is usually contributed at the beginning of September and the other half in March. Biological control applications were authorized when the ecosystem became unstable. Pruning was performed but with no watering. The third sample of jujube fruits came from trees planted 20 years ago that are kept in the wild to serve as hedges in organic farming plots. Both areas are approximately 500 m apart. No fertilizer was added to wild-grown trees. Pruning was the only hedge maintenance conducted. All fruits were hand-picked on the same day in early September 2021. We adjusted the time of collection to the optimal point of consumption. The selected fruits were healthy and undamaged, with firm skin; however, differences in skin color depended on the sample (Figure 1).

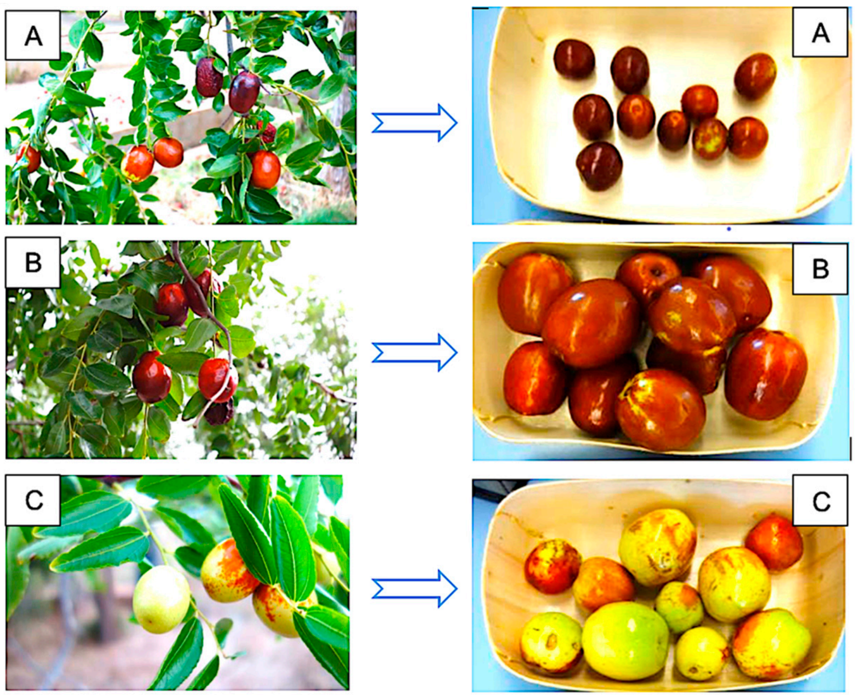

Figure 1. Details of the branches, leaves, and jujube fruits studied. Cultivate organic conditions: (**A**) small variety (ACP) and (**B**) large variety (ACG); (**C**) wild conditions (AS).

2.2. Preparation of Samples

We arbitrarily harvested approximately 1.5 kg of jujube fruits. We used whole fruits to measure their morphological characteristics. We washed the fruits, cut them longitudinally, and removed their seeds to analyze these characteristics. The pitted fruits were used for analytical quantification. Each fresh sample was divided into three fractions, and one was dried in an oven (3P-092 model J.P. Selecta, Barcelona, Spain) at 75 ± 0.1 °C to constant weight. The dried fraction was crushed (Retsch KG-5657 Haan, Remscheid, Germany) to obtain a homogeneous powder (250 μm) and stored in high-density polyethylene jars under refrigeration conditions (4 °C) until further study. The dried and crushed fraction of the fruit was used to determine the proximate and mineral composition.

We squeezed one part of the fresh fruit samples with a domestic juice extractor. Fresh juice was used to obtain total titratable acidity, pH, total soluble solids content, total and individual sugars, and vitamin C content.

We used another part of the fresh fruit to obtain a methanolic extract for determining total antioxidant activity. An aqueous extract was used to determine the total phenolic content. Methanolic extract was prepared by mixing 0.8 g of fresh homogeneous fruit in 5 mL of methanol solution (80% *w*/*v*). This mixture was stirred for 1 h at room temperature using an orbital shaker (Stuart Scientific, Chelmsford Essex, UK). An aqueous extract was obtained by grinding the fresh fruits with distilled water in a ratio of 2:1 (solvent:fruit) at a temperature < 30 °C using mechanical grinding. We used the extracts immediately in our respective analyses.

2.3. Morphological Characterization

We morphologically characterized the jujube fruits using the parameters of unit weight (W), height (H), diameter (D), geometric mean diameter (Dg), volume (V), surface area (S), and degree of sphericity (Ø). We measured fruit weights using an analytical balance (CB-Junior, Cobos, Barcelona, Spain) with an accuracy of ±0.01 g. An electronic digital sliding caliper (model CD-15 DC; Mitutoyo Ltd., Telford, UK) was used to measure fruit dimensions. Fruit volume was calculated using the adapted formula for a sphere:

$$V = \frac{3}{2}\pi\left(\frac{H}{2} + \frac{D}{2}\right)D^2$$

The fruits' mean geometric diameter was calculated by Dg = $(H\,D^2)^{1/3}$, the degree of sphericity as Ø = Dg/H, and the surface area (S) of the fruit using S = πDg^2 [28]. Thirty fruits from each group were used for morphological measurements.

2.4. External Color

We measured the CIE's (Commission Internationale de L'Eclairage) color parameters for the peel surface of 30 fruits using a Minolta Chroma meter (CR 200/08; Minolta Company, Osaka, Japan) [29]. Results were expressed as lightness (L*), redness (a*), and yellowness (b*) values (CIELAB coordinates). The L* represents lightness (100 for white and 0 for black) and chromatic coordinates are a* CIE red (+)/green (−) and b* CIE yellow (+)/blue (−) color attributes.

We calibrated the instrument at the beginning of each measurement session with approved tables or standards. The target color C* and Hue angle h* were calculated by the formulas:

$$h^* = \text{arctg}\frac{b^*}{a^*}$$

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

2.5. Nutritional Characteristics

We adjusted and optimized analytical methods to specifically analyze this type of matrix (jujube fruits). Three replicates were performed for each analysis.

2.5.1. Proximate Composition

We used the following methods in our analysis: moisture (AOAC 984.25); crude protein was obtained by multiplying the nitrogen value (Kjeldhal method) by 6.25 [30] (AOAC 984.13); crude fat was determined by extraction using petroleum ether as the solvent (AOAC 983.23); crude fiber was determined by the sequential reaction of dilute acids and bases (AOAC 962.09) and ash (AOAC 923.03). The carbohydrate content was calculated by differences: Carbohydrate = 100 − % (crude protein + crude fat + crude fiber + moisture + ash).

Nutritional profile results were expressed in g·100 g^{-1} fresh weight (fw). The energy was calculated by multiplying 9 kcal grams of fat, 4 kcal grams of protein, and 100 g of carbohydrates from edible and fresh fruit.

2.5.2. Mineral Composition

Jujube fruit samples were subjected to digestion according to the AOAC 985.35 method. The ashing of the samples was conducted in a Carbolite CWF 1100 chamber furnace at 550 °C. The ashes were dissolved in concentrated HCl until a 2% solution was obtained. Standard concentrations for each element were used in the calibration curves. The analytical curves were obtained with a linear response to the selected concentration ranges. We conducted a mineral analysis (Mg, Ca, Fe, Cu, and Zn) of each element using atomic absorption spectroscopy in a Thermo elemental AA series Spectrometer, v.11.03 software, and hollow cathode lamps. We analyzed sodium and potassium by flame photometry using a Jemway PF7 flame photometer (Jenway, Essex, UK) and phosphorus using spectrophotometry UV/V (Jenway 6715/UV-V) (Stone, UK) [31].

2.5.3. Total Titratable Acidity and pH

The total titratable acidity was obtained potentiometrically by titrating a 100 mL diluted (1:5) sample of juice with a 0.1 N NaOH solution to pH 8.1. The results were expressed as a percentage of citric acid. pH was measured directly in juice by a pH-meter with GLP 22+ (Crison, Barcelona, Spain) equipment and a glass electrode.

2.5.4. Total Sugars

The total sugar content of fruits was based on the anthrone colorimetric method [32]. We mixed 1.25 mL of fruit juice with 2.5 mL of anthrone reagent for 15 min at 10–15 °C and another 15 min at 100 °C. Afterward, it was cooled for 1 h at room temperature so that the color could develop. The absorbance was read at 625 nm by a spectrophotometer (Schott UV line 9400, Essex, UK). The results are expressed in g·100 g^{-1} fw.

2.5.5. Individual Sugars: Glucose, Fructose, and Sucrose

We used an enzymatic kit to determine the D-glucose and D-fructose content. The sucrose determination was performed after hydrolysis in HCl at 70 °C. Sucrose was hydrolyzed and decomposed into glucose and fructose monosaccharides, which were determined enzymatically. The absorbance was read at 340 nm with a thermostatizable cuvette by spectrophotometer (Schott UV line 9400, Essex, UK). The results are expressed in g·100 g^{-1} fw.

2.5.6. Total Soluble Solids

We determined the total soluble solids content of each sample using a hand-held refractometer with a range of 0–32 °Brix. This analysis was performed according to the refractometric method [31]. The results were expressed in °Brix at 20 °C.

2.6. Bioactive Components

2.6.1. Total Phenolic Content

We determined the total polyphenols by modifying the Folin–Ciocalteu method according to Arnous et al. [33]. We mixed 50 µL of the aqueous extract with 500 µL of the Folin–Ciocalteu reagent (previously diluted with water 1:10 *v*/*v*). We also added 500 µL of 6% (*w*/*v*) Na_2CO_3 solution to this mixture. We agitated the mixture for 10 s and allowed it to stand for 1 h at room temperature for color development. The absorbance at 750 nm was measured by a spectrophotometer (Jenway 6715/UV-V, Stone, UK), using gallic acid as standard. The results were expressed as mg gallic acid equivalents per 100 g of fresh weight (mg EAG 100 g^{-1} fw).

2.6.2. Total Antioxidant Capacity

We analyzed total antioxidant activity using a modified method [34,35] based on capturing the free radical DPPH. The methanolic extracts of the sample were used to measure absorbance at a 515 nm wavelength by a UV/V spectrophotometer, extrapolating the result of the DPPH-absorbance curve and expressing it as µmol Trolox equivalent (TE) per 1 g of fresh weight (µmol TE·g^{-1} fw).

2.6.3. Ascorbic Acid

The fruits' vitamin C (L-ascorbic acid) concentration was determined by the potentiometric titration method with chloramine T. We used automatic titration equipment with a Pt electrode (702 SM Titrino, Metrohm, Herisau, Switzerland). The results were expressed as mg 100 g^{-1} fw.

2.7. Statistical Analysis

Measurements of each parameter were completed in triplicate. The data obtained were processed using Statgraphics Plus version 5.1 software (Manugistics Inc., Rockville, MD, USA) for statistical means, standard errors, correlations, and other functions. Differences between the cultivars' effects were tested using an ANOVA one-way analysis. Differences between groups were identified with the F-test and Kruskal–Wallis test, which compares medians instead of means at the 95% confidence level. The Kruskal–Wallis test examined the null hypothesis of whether the median values within each of the three jujube fruit types were the same. The Kruskal–Wallis test requires that the populations are normal, independent, and present homoscedasticity. Pearson's linear coefficients of correlation (r^2) between traits were calculated (n = 9) from regression analyses between pairs of traits.

3. Results

3.1. Morphological Characterization and External Color

Table 1 presents the morphological characteristics and external color results of the jujube fruits. It is remarkable that most of the parameters studied were significant at the 95% confidence level according to ANOVA, except for degree of sphericity, which was not different.

Table 1. Mean value with standard deviation and coefficient of variation for jujube fruits' morphological characteristics and color parameters under organic crop conditions: small variety (ACP), large variety (ACG), and wild conditions (AS).

		Jujubes Fruits						
		Organic Crop System				Wild System		
		ACP	CV (%)	ACG	CV (%)	AS	CV (%)	*p*-Value
Morphological parameters	Weight (g)	4.96 ^{c} ± 1.10	22.17	28.67 ^{a} ± 5.69	19.83	18.79 ^{b} ± 9.25	49.22	0.0000
	Diameter (mm)	20.31 ^{c} ± 1.53	7.54	38.31 ^{a} ± 2.88	7.51	32.95 ^{b} ± 5.00	15.18	0.0000
	Length (mm)	21.78 ^{c} ± 1.57	7.19	42.86 ^{a} ± 3.20	7.46	35.07 ^{b} ± 5.09	15.51	0.0000
	Volume (mm^3)	18,454.9 ^{c} ± 4020.04	21.78	126,616.0 ^{a} ± 27,837.30	21.99	82,446.0 ^{b} ± 37,284.00	45.22	0.0000
	Geometric diameter (mm)	20.79 ^{c} ± 1.48	7.13	39.76 ^{a} ± 2.80	7.04	33.64 ^{b} ± 4.99	14.84	0.0000
	Degree of sphericity	0.95 ^{a} ± 0.03	2.95	0.93 ^{a} ± 0.03	3.47	0.96 ^{a} ± 0.02	2.54	0.6561
	Surface area (mm^2)	1363.66 ^{c} ± 194.00	14.23	4989.72 ^{a} ± 705.12	14.13	3629.84 ^{b} ± 1084.34	29.87	0.0000
External color	a*	13.37 ^{a} ± 3.48	26.02	12.93 ^{a} ± 2.63	20.37	8.33 ^{b} ± 6.07	72.83	0.0000
	b*	4.57 ^{c} ± 3.53	77.22	22.57 ^{b} ± 4.73	20.97	34.92 ^{a} ± 5.28	15.12	0.0000
	L*	85.74 ^{a} ± 2.85	3.32	62.44 ^{c} ± 3.24	5.20	77.84 ^{b} ± 8.02	10.31	0.0000
	C*	111.69 ^{c} ± 64.65	57.88	352.60 ^{b} ± 104.07	29.52	675.64 ^{a} ± 163.80	24.24	0.0001
	h*	0.30 ^{c} ± 0.21	69.48	1.04 ^{b} ± 0.14	13.00	1.33 ^{a} ± 0.20	15.06	0.0000

Notes: all data are expressed as mean value ± standard error for each parameter analyzed (n = 30); coefficient of variation (CV) and probability (*p*-value) for the differences between the jujube fruits type. Superscript letters (a–c) indicate statistically significant differences exist ($p < 0.05$).

The mean weight of the jujube fruits studied ranged between 4.96 and 28.67 g, with a diameter between 20.31 and 38.31 mm. The highest values of length, volume, geometric diameter, and surface area corresponded to the large variety (ACG), and the lowest values of these parameters corresponded to the small variety (ACP) under the same conditions. The morphological parameter values of the AS variety fruits are intermediate and between those of ACG and ACP. The differences found between the morphological parameters are statistically significant, except for the degree of sphericity. This parameter quantifies the isometry degree to reach the sphere shape. Regarding external color, the most luminous fruits were those of the large-caliber (ACG), and the least luminous were those of small caliber (ACP). Small-caliber fruits have the highest a* value, resulting in a redder skin and lower C* value. Wild fruits (AS) were more heterogeneous in skin color, combining green and reddish colors (Figure 2A–C), and consequently with a higher h* value.

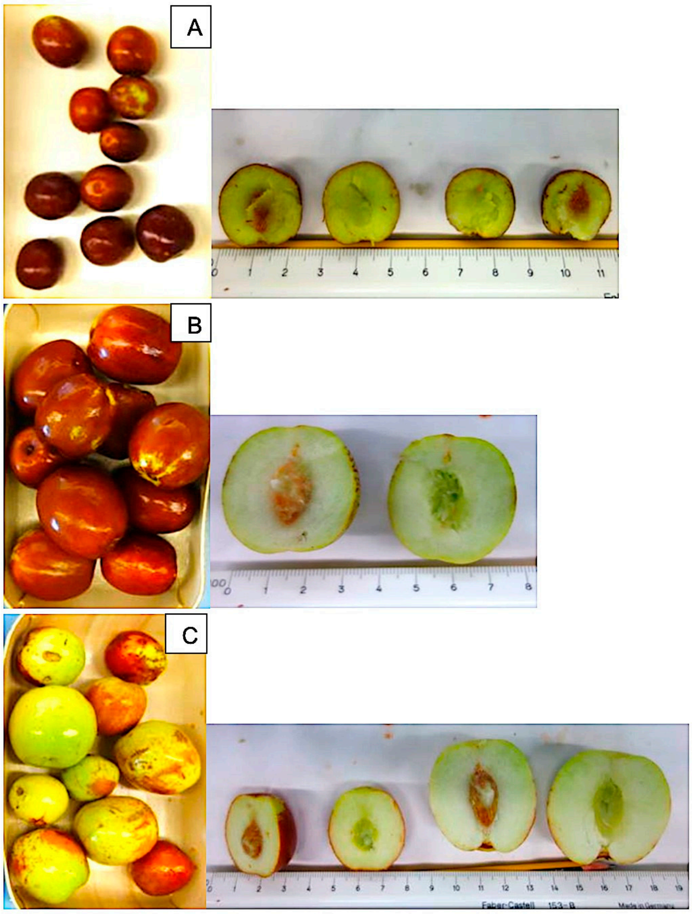

Figure 2. External and internal color aspects of: (**A**) small (ACP), (**B**) large (ACG), and (**C**) wild jujube fruits (AS).

The variability of the results is high for the unit weight of the fruits, regardless of the origin of the fruits. The coefficient of variation (CV) was also high in the a* and b* color parameters and, consequently, the variability of the target color C* and Hue angle h*.

3.2. Proximate and Mineral Composition

Table 2 summarizes the proximal profile and mineral composition of the analyzed jujube fruits in the three cultivar types, expressed as fresh weight (fw). Nutritional values include moisture, ash, protein, fat, fiber, and carbohydrate parameters and energy values. Mineral content included the most representative macro-minerals (Na, K, Mg, Ca, and P) and microminerals (Fe, Cu, and Zn). We considered statistically significant effects (*p*-value) in determining the contrast between the compositions based on each variety's growth environment. Table 2 presents these results. The superscript letters for each parameter studied show existing differences.

Table 2. Mean value with standard deviation and the coefficient of variation for jujube fruits' nutritional and mineral composition under organic crop conditions: small variety (ACP), large variety (ACG), and wild conditions (AS).

		Jujubes Fruits						
		Organic Crop System				**Wild System**		
		ACP	**CV (%)**	**ACG**	**CV (%)**	**AS**	**CV (%)**	***p*-Value**
Nutritional composition (g 100 g^{-1} fw)	Moisture	59.50 ^{c} ± 0.01	0.01	76.76 ^{a} ± 1.23	1.59	73.39 ^{b} ± 0.13	0.18	0.0000
	Ash	1.08 ^{a} ± 0.05	4.40	0.44 ^{b} ± 0.04	8.25	0.51 ^{b} ± 0.03	6.57	0.0000
	Fiber	1.21 ^{a} ± 0.33	27.39	0.91 $^{a\,\pm}$ 0.08	8.29	1.02 ^{a} ± 0.23	22.57	0.3486
	Fat	0.02 ^{b} ± 0.01	34.51	0.04 ^{a} ± 0.01	13.68	0.03 ^{b} ± 0.002	7.07	0.0122
	Protein	0.40 ^{a} ± 0.01	0.26	0.29 ^{b} ± 0.03	10.09	0.26 ^{b} ± 0.01	2.67	0.0000
	Carbohydrates	37.74 ^{a} ± 0.27	0.72	21.55 ^{c} ± 1.28	5.93	24.79 ^{b} ± 0.36	1.44	0.0000
	Energy value (kcal 100 g^{-1})	152.93 ^{a} ± 1.16	0.76	87.78 ^{c} ± 4.10	5.69	113.74 ^{b} ± 1.47	1.47	0.0000
Minerals composition (mg 100 g^{-1} fw)	Sodium	9.62 ^{a} ± 3.08	32.06	3.92 ^{b} ± 0.19	4.93	4.93 ^{b} ± 1.99	40.36	0.0351
	Potassium	226.18 ^{a} ± 0.69	0.31	90.42 ^{c} ± 12.14	13.43	119.72 ^{b} ± 7.00	5.85	0.0000
	Magnesium	19.66 ^{a} ± 2.85	14.50	8.11 ^{b} ± 1.39	17.13	7.48 ^{b} ± 2.04	27.23	0.0008
	Calcium	27.00 ^{a} ± 3.80	14.07	5.60 ^{b} ± 1.19	21.30	6.55 ^{b} ± 1.91	29.18	0.0001
	Phosphorus	176.52 ^{ab} ± 18.72	10.60	189.11 ^{a} ± 16.93	8.95	148.26 ^{b} ± 12.48	8.42	0.0533
	Iron	0.24 ^{a} ± 0.16	64.24	0.20 ^{a} ± 0.145	73.99	0.13 ^{a} ± 0.05	36.99	0.5951
	Copper	0.03 ^{a} ± 0.00	0.00	0.03 ^{a} ± 0.01	21.65	0.013 ^{b} ± 0.01	43.30	0.0110
	Zinc	0.12 ^{a} ± 0.03	20.41	0.07 ^{ab} ± 0.02	24.74	0.06 ^{b} ± 0.04	60.09	0.0598

Notes: all data are expressed as mean value ± standard error for each parameter analyzed (n = 3); coefficient of variation (CV) and probability (*p*-value) assess the differences between the jujube fruit types. Superscript letters (a–c) indicate statistically significant differences ($p < 0.05$).

Large-caliber jujube fruits (ACG) have the highest water content (76.76%) compared to wild fruits' moisture content (73.39%) and small-caliber fruits (ACP), which have the lowest water content (59.50%). The percentage of ash content indicates the total mineral concentration of the jujube fruits. There are significant differences in this parameter: small-caliber fruits have the highest mineral concentration compared to large-caliber (0.44%) and wild fruits (0.51%). Dietary fiber comprises a group of components, such as polysaccharides and lignin, which are resistant to enzymes during human digestion.

All jujube varieties have a high fiber content (average 1.05%). They were mainly characterized by a low-fat content between 0.02 and 0.04%, with the large-caliber fruits being the fattiest in the study. Jujube fruits are also characterized by low protein levels, with the small-caliber fruits having the most protein (0.4%) compared to the large-caliber and wild fruits. Carbohydrates are the main nutrients in jujube fruits. Small fruits had the maximum carbohydrate levels (37.7%) followed by wild fruits (24.79%). The fruits' energy values show the same trend as carbohydrates. The ranges vary statistically from 87.78 to 152.93 kcal·100 g^{-1} fresh weight, with higher levels in small jujube fruits.

The coefficient of variation (CV) differed from other nutritional parameters such as fiber and fat in the three fruit types studied. The remaining parameters were less variable, with coefficients of variation oscillating between 0.01 and 1.47%. Moisture was the most stable fruit parameter. The high coefficient of variation values found in some parameters may be due to fewer evaluations.

In all three fruit types, the most abundant mineral was potassium with significant differences between growing conditions (p = 0.0000). The small-caliber fruits accumulated the highest potassium concentration (226.18 mg 100 g^{-1} fw), followed by wild fruits (119.72 mg 100 g^{-1} fw) and larger fruits (90.42 mg 100 g^{-1} fw). Phosphorus is the second most abundant mineral element in jujube fruits. The larger fruits differ from wild fruits in their phosphorus accumulation. The third mineral element in abundance in jujube fruits is calcium. The concentrations of this element are higher for small fruits (27.00 mg 100 g^{-1} fw), followed by the wild fruits (6.55 mg 100 g^{-1} fw) and large fruits (5.60 mg 100 g^{-1} fw). Significant differences were observed between small fruits' calcium content and the rest. This same trend was observed for magnesium content, which was predominant in small fruits (19.66 mg 100 g^{-1} fw), differing significantly from the concentrations of the other two provenances. On the other hand, large fruits exceeded the magnesium concentration of wild fruits. Sodium is the macro-mineral with the lowest content in all jujube fruit varieties. Its presence in the fruits follows the same trend as that of calcium. Regarding mineral microelements, jujube fruits have the highest concentration of iron, followed by zinc and copper in lower concentrations. Small fruits had the highest concentration of all mineral microelements, whereas wild fruits had the lowest. The iron values oscillated between 0.13 mg 100 g^{-1} fw (AS) and 0.24 mg 100 g^{-1} fw (ACP), with no statistically significant differences between the three fruit types. Zinc content in jujube fruits oscillated between 0.06 mg 100 g^{-1} fw (AS) and 0.12 mg 100 g^{-1} fw (ACP), with statistical differences between both values. Copper concentrations ranged between 0.013 mg 100 g^{-1} fw (AS) and 0.03 mg 100 g^{-1} fw (ACP and ACG), with statistical differences between both.

3.3. Acidic and Sugary Components

Table 3 summarizes the sugary (total sugars, glucose, fructose, sucrose, and soluble solids) and acidic (pH and total titratable acidity) components of the three studied jujube fruits in the three cultivar types.

Table 3. Mean value with standard deviation and coefficient of variation for sugary (total sugars, glucose, fructose, sucrose, and soluble solids total) and acidic (pH and total titratable acidity) contents of jujube fruits under organic crop conditions: small variety (ACP), large variety (ACG), and wild conditions (AS).

		Jujubes Fruits						
		Organic Crop System				Wild System		
		ACP	CV (%)	ACG	CV (%)	AS	CV (%)	*p*-Value
Sugary	Total sugars (g·100 g^{-1} fw)	5.30 ^{a} ± 1.51	28.54	4.16 ^{a} ± 2.65	23.62	5.32 ^{a} ± 2.21	21.58	0.7661
	Glucose (g·100 g^{-1} fw)	3.35 ^{a} ± 0.92	27.39	2.35 ^{a} ± 1.45	21.89	3.28 ^{a} ± 1.57	28.02	0.6207
	Fructose (g·100 g^{-1} fw)	0.63 ^{a} ± 0.63	29.95	0.43 ^{a} ± 0.07	15.49	0.81 ^{a} ± 0.53	24.97	0.6417
	Sucrose (g·100 g^{-1} fw)	0.97 ^{a} ± 1.11	15.09	1.38 ^{a} ± 1.22	28.04	1.22 ^{a} ± 0.27	21.80	0.8711
	Total soluble solids (°Brix)	31.02 ^{a} ± 0.16	0.52	23.27 ^{b} ± 0.42	1.79	22.10 ^{c} ± 0.27	1.20	0.0000
Acidic	pH	3.83 ^{a} ± 0.02	0.54	4.33 ^{a} ± 0.09	2.07	4.07 ^{a} ± 0.38	9.29	0.0931
	Total titratable acidity (%citric acid)	1.04 ^{a} ± 0.12	11.22	0.23 ^{c} ± 0.06	26.90	0.43 ^{b} ± 0.15	33.45	0.0003
	Total sugars/total acids ratio	5.24 ^{a} ± 2.09	39.86	17.38 ^{a} ± 11.00	63.31	12.89 ^{a} ± 5.17	40.08	0.1889

Notes: all data are expressed as mean value ± standard error for each parameter analyzed (n = 3); coefficient of variation (CV) and probability (*p*-value) for the differences between the jujube fruit types. Superscript letters (a–c) indicate statistically significant differences ($p < 0.05$).

The results of total sugar content presented great variability. Wild and small-caliber fruits had the highest concentrations of total sugars (proximally 5 g·100 g^{-1} fw) with no statistical differences between the concentrations of different fruits. There were no differences in the absolute values between individual sugars, and all jujube fruits presented similar values (2.35–3.35 g·100 g^{-1} fw for glucose, 0.43–0.81 g·100 g^{-1} fw for fructose and 0.97–1.38 g·100 g^{-1} for sucrose). Glucose is the major sugar contained in all fruit varieties. Sugars in fruit represent approximately 75% of the soluble solids content. The total soluble solids of jujube fruits were detected at concentrations between 22.1–31.02 °Brix, with the smallest variety having the highest concentration (p = 0.0000) and the wild having the lowest. The most acidic pH values were found in small jujube fruits at 3.83, which also had the highest total titratable acidity, with 1.04% expressed as citric acid. It should be noted that there were no significant differences in pH (p = 0.0931) between jujube fruits. However, there were significant differences in total acidity, with the largest fruits having the lowest acidity.

In general, the acidity of jujube fruits is low, which accounts for the fruit's sweet sensation by promoting a high total sugars/total acids ratio. The relative standard deviation was large in some cases. The bioactive components studied in jujube fruits were total antioxidants, total polyphenols, and ascorbic acid. Table 4 summarizes the concentrations of these components.

Table 4. Mean value with standard deviation and coefficient of variation of bioactive components (total antioxidants capacity, total polyphenols, and ascorbic acid) of the jujube fruits under organic crop conditions: small variety (ACP), large variety (ACG), and wild conditions (AS).

	Jujubes Fruits						
	Organic Crop System				**Wild System**		
	ACP	**CV (%)**	**ACG**	**CV (%)**	**AS**	**CV (%)**	***p*-Value**
Total antioxidants capacity (µmoles ET·100 g^{-1} fw)	241.31 [ab] ± 18.00	7.46	213.74 [b] ± 7.85	3.67	243.14 [a] ± 15.57	6.40	0.0827
Total polyphenols (mg EGA·100 g^{-1} fw)	630.81 [a] ± 33.84	5.37	480.83 [b] ± 83.57	17.38	520.71 [ab] ± 49.25	9.46	0.0500
Ascorbic acid (mg 100 g^{-1} fw)	441.13 [a] ± 31.56	7.16	286.10 [b] ± 17.62	6.16	303.06 [b] ± 16.01	5.28	0.0003

Notes: all data are expressed as mean value ± standard error for each parameter analyzed (n = 3); coefficient of variation (CV) and probability (*p*-value) for the differences between the jujube fruits type. Superscript letters (a,b) indicate statistically significant differences exist ($p < 0.05$). ET: equivalent Trolox and EGA: equivalent gallic acid.

3.4. Bioactive Components

The total antioxidant content in fresh fruits ranged from 213.74 (ACG) to 243.14 (AS) (µmoles ET·100 g^{-1}). The total phenolics were higher in the small variety at 630.81 (mg GAE·100 g^{-1}). Vitamin C content varied between 286.10 (ACG) and 441.13 (ACP) (mg 100 g^{-1}). The trend between total phenolics and vitamin C content was similar. Small jujube fruits had the highest content, followed by wild and large fruits, which synthesized less bioactive compounds. We found significant differences between the values of small- and large-caliber fruits. For total antioxidants, wild fruits contained the highest concentration, with significant differences compared to large-caliber fruits under organic conditions.

4. Discussion

Jujube trees are very adaptable to severe environments and high summer temperatures. The loss of leaves during latency slows down its growth and saves energy. Furthermore, it is tolerant of arid and low-input conditions due to its robust tap root system, which intakes water and nutrients from a deeper soil profile [36]. Our comparative study is based on the size of jujube fruits and their production conditions in the same growing zone. The largest and smallest fruits belong to different varieties of trees receiving organic fertilization, irrigation, and biological pest control compared to wild trees, whose fruits show morphological differences compared to the other two types of fruits by being exposed to the environment.

The individual weights of jujube fruits in our study are within the range cited by other authors in Korean [37,38], Chinese [39], and Spanish cultivars [18,40] for small (1.9 g) and high unit weights (22 g). They found that variety was the main factor influencing the weight of the fruits. The dimensions (diameter and length) of the three jujube fruit types were within the interval of values reported by authors [26], who placed the diameter range between 16.64 and 38.87 mm and the fruit length between 21.78 and 42.86 mm. Morphologically, the longitudinal and transversal dimensions of the fruits are fundamental because they help obtain information on other parameters such as the volume and surface of the fruits. These data are useful in fruits' commercial aspect, such as transport or conservation, and their influence on reducing food waste [41]. Since the degree of sphericity for the three fruit types is similar, it is considered a structural criterion of jujube fruits. However, the relationships between volume and surface area and volume/weight vary between types of fruit. These criteria must be considered during the colder months in postharvest or in packaging.

Jujube fruits turn from an immature green to reddish when ripe [37]. The color and its homogeneity are essential to consumer acceptance. The color parameter data provided by Wang et al. [39] differed from the present study due to cultivation factors, geographic location, genotype, and especially maturity stage. Research [40] under Mediterranean cultivation conditions characterized jujube fruits by luminosity values > 71. Low values of a* and high values of b* in the pulp suggest that the jujube fruits have yellow-colored pulps that differ from the green-colored pulps of the fruits in the present study. Jujubes are non-climacteric fruits and can be consumed in a wide range of ripening stages. Harvest variation and the fruits' maturity stage may be the cause of the differences found.

Rashwan et al. [42] collected nutritional information on jujube fruits as containing 77.86% moisture, 20.23% carbohydrates, 1.20% protein, 0.2% fat, and 0.51% ash, providing a calorific value of 79 kcal per 100 g of fresh fruit. Fresh Korean jujube fruits also reported variable results with 71.46–72.90% moisture, 1.37–1.71% crude protein, 0.31–0.33% fat, 0.71–1.11% ash, and 2.92–4.16% dietary fiber contents [43]. In Chinese jujube fruits, the authors of [11] found that the moisture content, total dietary fiber, and protein ranged from 64.31–76.50%, 4.85–7.32%, and 1.87–3.97%, respectively. Furthermore, they typified the proximal composition of five Chinese jujube fruit cultivars and found variable results [44]. In all cases, slight deviations were due to differences between cultivars and production systems. Some authors have recorded average moisture levels of jujube fruits at 83% [45], while others have provided greater variability in the results, recording values ranging between 64.7 and 81.4%, depending on the morphological variability and cultivar of the fruits [46,47].

The beverage industry might be interested in jujube fresh juice derived from fruits with high water content for the highest juice yield. The main difference between the macronutrients of jujube fruits under low-input conditions and data from the literature is protein content. Considering the close relationship between fertilizing nitrogen and/or sources of organic matter and the protein levels of plant material, it is possible that the differences found between the literature and the present study are due to the low inputs of fertilization received.

Jujube fruits are low-calorie foods due to their low fat, protein, and carbohydrate values. Therefore, they are recommended for low-calorie diets. High-caliber fruits from organically grown trees have the lowest dry matter content and, consequently, the lowest energy value (87.78 kcal/100 g of fresh fruit). Differences may be due to variability in water content and the fruits' other caloric nutrients.

Jujube fruit is a moderate source of macro- and micro-minerals such as P, K, Ca, Mg, Fe, Cu, Zn, and Na (34.2, 298, 15.2, 14.7, 1.99, 0.073, 0.16, and 15.2 mg 100 g^{-1} fw, respectively) [48]. Under Spanish conditions [40], the range of minerals (mg in 100 g of fresh jujube fruit) was as follows: K = 317–461, Ca = 6.13–19.2, Mg = 10.66–20.52, Fe = 0.27–0.46, Cu = 0.01–0.032, Zn = 0.11–0.13 and Na = 2.93–11.46. In Korean [43] and Chinese jujubes [44], mineral concentrations are within the ranges described, with slight variations compared to the present study. The mineral content of the fruits may have been affected by climate, soil type, harvest time, genetic factors, environmental conditions, and agronomic techniques. However, we can confirm that the low-input conditions of the present study did not influence mineral absorption. Therefore, the three jujube fruit types had coherent concentrations of macro- and micro-elements.

In jujube, the major sugars are glucose and sucrose, with fructose being the less abundant sugar. This tendency agrees with Gao et al. [47]. However, under Spanish conditions [18,40] the maximum sucrose content is obtained, whereas under Chinese conditions [44,49,50], the maximum fructose and glucose contents were found but almost no sucrose. Genetic factors are responsible for variations in biochemical reactions such as the hydrolysis of pectins and the metabolism of sugars and acids during fruits' development and ripening. Specifically, the acidic components decrease, whereas carbohydrates increase significantly and gradually in the fruit, but with differences between the individual sugars. While some studies have reported an increase in sucrose and fructose and a decrease in glucose during the ripening stage [51], others have reported a reduction in sugars [52], showing that sucrose degradation occurs with a simultaneous increase in the synthesis of glucose and fructose [53].

The total sugars/total acids ratio provides information about the fruit flavor. The small variety of jujube fruits has a value of around 5, specifying a moderate acid taste despite being sugary. The sweet flavor evidently predominated in the large fruit variety and under wild conditions, with a ratio of 12.87 and 17.38, respectively. These levels were comparable to those reported for Chinese and Spanish jujube cultivars with a similar maturity stage [39,40,49]. Consequently, low-input conditions are ideal for producing sweet fruits for fresh consumption and reducing added sugars in the food industry.

Vitamin C content is a key indicator used to estimate the nutritional quality of fruits. Rashwan et al. [42] indicated that jujube fruits' vitamin C content can vary between 70 and 550 mg 100 g^{-1} fw. Specifically, Li et al. [44] cited the range of ascorbic acid in five Chinese jujube cultivars as 192–359 mg 100 g^{-1}. In Spanish [40] jujube cultivars, the range of vitamin C content was found between 410 and 640 g 100 mL^{-1}. In two cultivars of Korean jujubes, vitamin C content was lower (29.00–37.67 mg 100 g^{-1} fw) [43]. According to Chen et al. [11], Chinese jujube cultivars also showed a significantly higher vitamin C content from 162.50 to 244.58 mg 100 g^{-1} fw. Gao et al. [47] also observed a wide variation (225.1–387.9 mg 100 g^{-1}) in ascorbic acid content in jujube cultivars. The vitamin C concentrations obtained from jujube fruits under low-input conditions in the Mediterranean are higher than those in Asian crops. Organically produced small-caliber fruits and wild fruits synthesize the highest concentrations of this important vitamin. When resources are scarce, jujube fruit can be a potential source of vitamin C.

Jujube is documented as one of the richest sources of functional foods due to its high concentration of total polyphenols. Polyphenol-rich foods help prevent cardiovascular diseases, cancer, and neurodegenerative diseases [17]. Phenolic compounds can block free radicals, and superoxide and hydroxyl radicals through single electron transfers. Our study was comparable to other studies on Asian fruits by showing similar total polyphenol concentrations in jujube fruits. In Spanish jujube cultivars, Reche et al. [54] found concentrations of total polyphenols similar to those in the present work, with small-caliber fruits having the highest values. In addition, the total polyphenol content decreased as the fruit matured. Wu et al. [49] cited the range of total polyphenols in jujube cultivars as 275.6–541.8 mg EGA·100 g^{-1} fw. These concentrations are higher than those found in other common fruits known for their high total polyphenol content. The relatively high amount of polyphenol content may be due to the low-input conditions under which the jujubes in our study were grown. Stress conditions can promote polyphenol synthesis, thus exhibiting higher antioxidant activities than fruits grown under high-input conditions. In this sense, jujube fruits synthesize higher concentrations of antioxidant substances under arid conditions [49].

Figure 3 shows the relative value of vitamin C content and total polyphenols from published data about fruits and vegetables with the highest consumption compared to low-input growth jujube fruits studied in this work. Small-sized jujube fruits grown in organic conditions have the highest concentration of vitamin C and total polyphenols at 100%. The concentrations registered in the literature for the most commonly consumed fruits and vegetables have a relative value. Jujube fruits grown in low-input conditions are at the base of the vitamin C and polyphenol composition pyramid, differing from commonly consumed fruits and vegetables. For example, parsley has a high vitamin C content (168.4 mg 100 g^{-1} fw), with an equivalent of 38.17% in ACP jujube fruits. Despite foods with high vitamin C values, such as parsley or red pepper (higher concentrations if cultivated organically), these concentrations can be affected by cooking or the food's nutritional density. Furthermore, consuming 100 g of parsley is more difficult than consuming 20 g of jujube fruits. Similarly, 100 g of red pepper can lose nutrients after cooking compared to eating fresh jujube fruits.

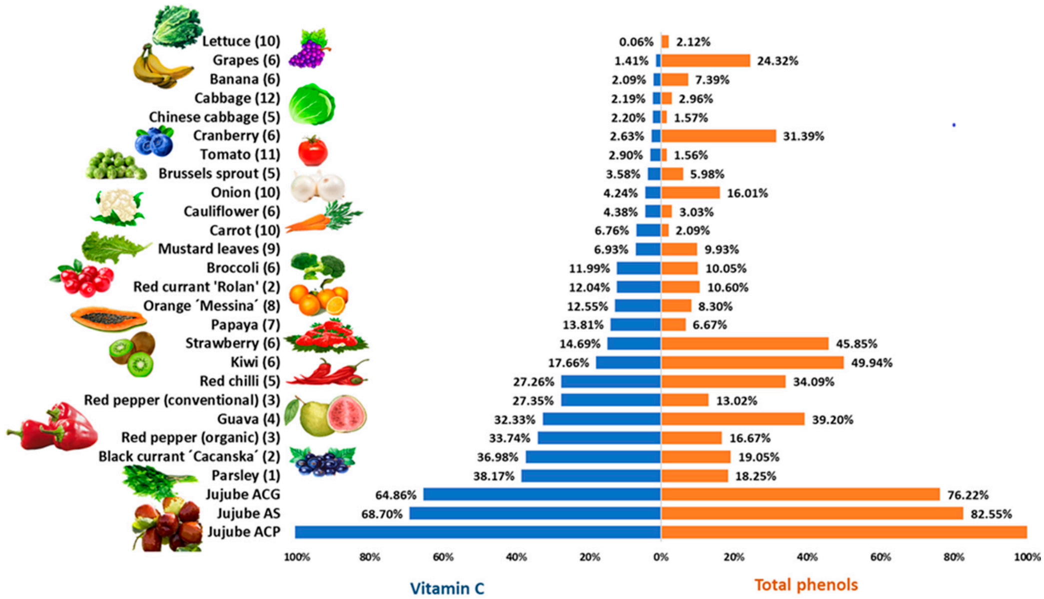

Figure 3. Relative value of vitamin C content and total polyphenols in fruits and vegetables with the highest consumption compared to jujube fruits of low-input growth (small, ACP; large, ACG; and wild, AS). (1) [55]; (2) [56]; (3) [57]; (4) [58]; (5) [59]; (6) [60]; (7) [61]; (8) [62]; (9) [63]; (10) [64]; (11) [65]; (12) [66].

Bioactive compounds differ widely in composition and ratio from fruits and vegetables, particularly in vitamin C and polyphenol compounds (Figure 3). However, the synthesis mechanisms are complementary in low-input jujube fruits, whose health benefits have been reported with consumption.

In the jujube fruits studied, a weak non-significant positive correlation was obtained between total polyphenols and total antioxidant capacity (r^2 = 0.4940). There is agreement that antioxidant capacity is directly related to phenolic compounds. However, we did not find a positive correlation between the total polyphenolic content and the antioxidant capacities for five types of vegetable extracts [67]. Reche et al. [68] found a significant positive correlation between total polyphenols and hydrophilic total antioxidant activity in Spanish jujube fruits. In studies with Chinese jujube, Pearson's correlation analysis did not show any relationship between total phenolic concentrations and antioxidant capacities nor between antioxidant capacity and vitamin C content [69]. Consequently, phenolic compounds may increase antioxidant capacity because they can scavenge free radicals as well as superoxide and hydroxyl radicals. However, they are not the only factor influencing antioxidant capacity. Other bioactive substances such as vitamin C and pigments also contribute. In addition, the synergistic effects between them must be considered, which favor total antioxidant capacity. In this study, a weak positive correlation was obtained between total antioxidant capacity in the jujube fruits and vitamin C content (r^2 = 0.4711). Higher relationships (r^2 = 0.79) were also found between these parameters [8].

Vitamin C accumulation in jujube fruits produced under low-input conditions is highly conditioned by potassium concentration. Both parameters have a strong positive relationship (r^2 = 0.9378), as indicated by the equation: Vitamin C = 170.964 + 1.18581 $\times$ K. This relationship has also been observed in other fruits, such as tomatoes [70]. Potassium excretion and plasma vitamin C concentration are two biomarkers for evaluating humans' fruit and vegetable consumption [71].

5. Conclusions

Under low-input conditions, jujube trees are more resilient to adverse climate situations and provide nutritional and environmental sustainability because of special morphological and biochemical fruit characteristics. Jujube fruits are a high-yield food resource because they adapt to low-input conditions and adverse ecological environments. Their antioxidant properties (high total polyphenol content and high vitamin C concentrations) and their high mineral content position them as fruits with important beneficial effects on human health. In addition, the fruits have a favorable taste due to a balance between sugars and acids.

Significant differences in the fruits' size, shape, and color parameters were identified, mainly due to differences between cultivars. These differences do not affect the fruits' degree of sphericity, which is the structural criterion for jujube fruits. Jujube fruits under low-input conditions are an excellent dietary source of vitamin C; therefore, identifying new sources of this vitamin is important to public health. Jujube fruits can be classified as "high in vitamin C". A small piece of fruit (ACP) weighing 20 g can provide the daily vitamin C needs of an adult person. Its high vitamin C and mineral content provides beneficial health effects and reduces the risk of some diseases.

In Spain, the jujube is an undervalued fruit with little economic value. The excellent nutritional properties of jujube fruits and tree's tolerance for low inputs could be used to enhance studies on cultivating fruit varieties with greater profitability and applicability and possibly extend to the food industry based on crop recovery and fruit consumption.

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