Antioxidant Capacities of Jujube Fruit Seeds and Peel Pulp

Yung-Sheng Lin 1,2,3,*, Wen-Shin Lin 4, Jing-Wen Tung 1, Ya-Chih Cheng 1, Min-Yun Chang 1, Cheng-You Chen 2 and Shu-Ling Huang 1,2

1 Department of Chemical Engineering, National United University, Miaoli 36063, Taiwan; tung.whitebear@gmail.com (J.-W.T.); yccheng9867@gmail.com (Y.-C.C.); mino101451@gmail.com (M.-Y.C.); simone@nuu.edu.tw (S.-L.H.)
2 Program in Materials and Chemical Engineering, National United University, Miaoli 36063, Taiwan; wayne20410@gmail.com
3 Institute of Food Safety and Health Risk Assessment, National Yang-Ming University, Taipei 11221, Taiwan
4 Department of Plant Industry, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan; wslin@mail.npust.edu.tw
* Correspondence: linys@nuu.edu.tw; Tel.: +886-37-382199

Received: 15 July 2020; Accepted: 27 August 2020; Published: 30 August 2020

Abstract: In this study, the effects of different fruit parts and extraction conditions on the antioxidant properties of jujube (Ziziphus jujuba Mill.) fruit were investigated. Five in vitro antioxidant models and statistical analyses were performed. The results revealed that jujube peel with pulp exhibited better antioxidant capacity than did seeds. Overall, jujube peel pulp extracted using 50% ethanol at 60 °C exhibited the best antioxidant capacity in terms of 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (0.3 ± 0 mg/mL), 2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging activity (0.5 ± 0 mg/mL), total phenolic content (38.3 ± 0.4 mg gallic acid equivalent per gram dry weight), total flavonoid content (43.8 ± 0.2 mg quercetin equivalent per gram dry weight), and reducing power (41.9 ± 2.2 mg ascorbic acid equivalent per gram dry weight). The results indicated that jujube peel pulp is a more potential natural antioxidant than seeds.

Keywords: Ziziphus jujuba; jujube; antioxidant; peel; pulp; seed; extraction

1. Introduction

Jujube (Ziziphus jujuba Mill.) belongs to the Rhamnaceae family and grows in subtropical areas [1]. China, Spain, and India are the main producers of jujube [2]. Approximately 700 cultivars of jujube are produced in China [3]. Jujube is a medium or large deciduous tree and its fruits are oval or round. Unripe jujube fruits are green, smooth, and taste like apples. When ripe, the fruits turn red, brown, or purplish-black [4]. Jujube bark is used as a remedy for flatulence, diarrhea, and vomiting. Jujube leaves are used for cold relief, decongestion, and mitigating diabetes symptoms and are consumed as a tea. Jujube flowers have high-quality nectar. Jujube fruits are used in traditional Chinese medicine because of their antiaging, immunomodulative, anticancer, sedative, hypnotic properties and other effects [5–9].

Jujube fruit is rich in nutrients, including sugars, fatty acids, amino acids, polyphenols, flavonoids, fiber, and minerals such as calcium, magnesium, and iron [10,11]. Jujube is a seasonal fruit and deteriorates rapidly after harvesting; therefore, it is typically dried for storage [12,13]. It has been widely used as a food, a food additive, flavoring, and in processed forms such as jams, breads, cakes, and jelly [14,15].

There are different methods proposed to extract jujube fruit. Ji et al. used ultrasound-assisted aqueous two-phase extraction by an ethanol/ammonium sulfate system as a multiphase solvent to
extract polysaccharides from jujube fruit [16]. Liu et al. applied subcritical water extraction at specific temperatures (ranging from 110 to 150 °C) and six atmospheric pressures to extract polysaccharides from jujube fruit powder [17]. Wu et al. reported that ultrasonic extracts of pear-jujube fruit with methanol solution had a total phenolic content of 7.69 mg gallic acid equivalent (GAE) per gram fresh weight [18]. Furthermore, many solvent-based extraction methods were reported to extract jujube. For examples, Zhang et al. used 80% ethanol to extract jujube and found peel had a higher total phenolic content, 32.8 mg GAE per gram dry weight (DW), than pulp and seed [1]. Zhao et al. used 95% ethanol to extract seven cultivars of Chinese jujube and reported 4.54 to 12.99 mg GAE/g DW of extracts [19]. Choi et al. used 80% methanol solution to extract jujube fruit and found 11 to 24 mg GAE/g DW of pulp extracts [20]. Solvent-based extraction is the most widely used method for extraction of natural products. It offers an easy and convenient way for extraction and does not destroy compounds.

Gong-Guan, Miaoli, is the main area of jujube cultivation in Taiwan [21]. In this study, jujube fruit from Miaoli was used as the object of antioxidant research. Many papers have revealed that jujube fruits from Spain [22], China [19], India [23], and Taiwan [24] have considerable antioxidant capacities. Studies on the antioxidant capacities of jujube fruit have focused on extraction using different solutions or on comparison of the antioxidant capacities of different cultivars [10,13,19,25]. Limited information is available on the antioxidant capacities of different parts of jujube fruit. Therefore, this study investigated differences in antioxidant capacities between the seeds and peel pulp of Miaoli jujube fruit extracted using deionized (DI) water and 50% ethanol under different temperatures.

2. Methods

2.1. Reagents

1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), butylated hydroxytoluene (BHT) and Folin–Ciocalteu reagent were purchased from Sigma Chemical Co. (St. Louis, MO, USA). Aluminum chloride and quercetin were purchased from Alfa Aesar (Haverhill, MA, USA). Potassium persulfate and potassium ferricyanide were obtained from Showa Chemical (Tokyo, Japan). Phosphate buffer and sodium carbonate were purchased from Riedel-de Haën (Seelze, Germany). Gallic acid was obtained from Fluka (Neu-Ulm, Germany). Ascorbic acid, trichloroacetic acid and Trolox were obtained from Acros Organics (Fair Lawn, NJ, USA). Iron (III) chloride hexahydrate was purchased from J.T. Baker (Phillipsburg, NJ, USA). Ethanol and sodium hydroxide were obtained from Echo Chemical (Miaoli, Taiwan). All chemicals were of reagent grade and were used without further purification.

2.2. Preparation of Samples

Jujube fruit (Figure 1) were obtained from Kung-Kuan Farmers’ Association, Gong-Guan, Miaoli, Taiwan. The peel pulp and seeds of jujube fruit were separated by a separating device. After drying at 40 °C for 12 h, peel pulp and seeds were ground using a pulverizer for use in further extraction experiment. In the experiment, 5 g of peel pulp was extracted through oscillation using 40 mL of DI water and ethanol solutions with different concentrations for 1 h to study the effect of extract solutions. To investigate the effect of the fruit parts, both 5 g of seeds and 5 g of peel pulp were extracted with DI water and 50% ethanol by the same extraction procedure. After filtration, the extracted solvent was removed through lyophilization and rotary vacuum evaporation for DI water and ethanol solutions, respectively.
2.3. 2,2-Diphenyl-1-Picrylhydrazyl Radical Scavenging Activity

A modified version of the procedure described in [26] was used to determine 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity. A 2 mL tested sample solution was added to 2 mL of a 0.2 M DPPH solution and allowed to react in the dark at room temperature for 30 min. The absorbance of the reacted solution was measured at 517 nm using a Jasco V-530 spectrophotometer (Jasco Corporation, Tokyo, Japan). A lower absorbance indicated stronger DPPH radical scavenging activity.

\[
\text{DPPH radical inhibition (\%)} = (1 - \frac{A_{517\text{nm}}\text{ of sample}}{A_{517\text{nm}}\text{ of blank}}) \times 100\%
\]

2.4. 2,2-Azino-Bis-(3-Ethylbenzothiazoline-6-Sulfonic Acid) Radical Scavenging Activity

A modified version of a procedure described in [27] was applied to examine the 2,2-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging activity of the tested solutions. The ABTS stock solution was prepared through the reaction of 7 mM ABTS and 2.45 mM potassium persulfate. After storage in the dark at a temperature of 4 °C for 16 h, the working solution of ABTS was obtained by diluting the stock solution in ethanol to achieve an absorbance of 0.70 ± 0.02 at \( \lambda = 734 \text{ nm} \) by the spectrophotometer. Subsequently, 0.3 mL of the tested sample solution was added to 2.7 mL of the ABTS working solution and allowed to react for 10 min in the dark. The absorbance of the solution was measured at 734 nm. A lower absorbance reflects a stronger ABTS radical-scavenging activity.

\[
\text{ABTS radical inhibition (\%)} = (1 - \frac{A_{734\text{nm}}\text{ of sample}}{A_{734\text{nm}}\text{ of blank}}) \times 100\%
\]

2.5. Determination of the Total Phenolic Content

The total phenolic content was measured using a modified version of the method described in the literature [28]. The sample solution (0.4 mL) was added to 2 mL of the 10% Folin–Ciocalteu reagent. After 3 min, 1.6 mL of 7.5% sodium carbonate was added and incubated in a water bath at 45 °C for 15 min. The absorbance of the mixture was measured at 765 nm by the spectrophotometer. Gallic acid was used as the standard for the total phenolic content and the measured calibration curve of gallic acid was \[ y = 0.0124 x + 0.0243, \] where \( x \) and \( y \) were concentration and absorbance, respectively. The total phenolic content of the test sample is expressed as mg GAE/g DW of the extract.

2.6. Determination of the Total Flavonoid Content

The total flavonoid content was measured using a modified colorimetric version of the method described in [29]. Therefore, 1.35 mL sample extracts were added to 0.2 mL of a 5% sodium nitrite solution and reacted for 5 min, after which 0.4 mL of 10% aluminum chloride was added. After 5 min, 1.4 mL of 1 M sodium hydroxide was added. The absorbance of the mixture was measured at 510 nm by the spectrophotometer. Quercetin was used as the standard for the calibration curve to determine...
the total flavonoid’s content and the measured calibration curve of quercetin was $y = 0.0052x + 0.1547$, where $x$ and $y$ were concentration and absorbance, respectively. The flavonoid content is expressed as milligrams of quercetin equivalent (QE) per gram DW.

2.7. Reducing Power

The reducing power was measured using a modified version of the method described in [30]. The sample extracts (0.5 mL) were mixed with 1 mL of 0.2 M phosphate buffer. Next, 0.5 mL of 1% potassium ferricyanide was added. The mixture was then incubated in a water bath at 50 °C for 20 min and then cooled immediately. Next, 0.8 mL of 1% trichloroacetic acid was added, followed by the addition of 0.8 mL of 0.1% iron trichloride hexahydrate. The reaction was conducted in the dark for 10 min, and the absorbance of the mixture was measured at 700 nm by the spectrophotometer. Ascorbic acid was used as the standard and the measured calibration curve of ascorbic acid was $y = 0.0112x + 0.2912$, where $x$ and $y$ were concentration and absorbance, respectively. The reducing power is expressed as milligrams ascorbic acid equivalent (AAE) per gram DW.

2.8. Statistical Analysis

The experimental data are expressed as means ± standard deviations of three replicate determinations. To ensure statistical representation, means were compared between the treatment levels by using SAS software (version 9.4, SAS Institute, Cary, NC, USA). Statistical analyses were performed using analysis of variance. If the treatment produced a significant result ($p < 0.05$), then the treatment mean was compared with the result from Fisher’s least significant difference (LSD) test.

3. Results and Discussion

There are many ways to resist oxidation, such as providing electrons, blocking the chain reaction of free radicals, or chelating metal ions, such as copper and iron ions. Antioxidant systems in organisms can be divided into two categories, enzymatic antioxidants and non-enzymatic antioxidants. The enzyme-type antioxidant system is synthesized by the human body, mainly antioxidant enzymes, which convert free radicals in the body into more stable and non-toxic substances through redox effects. In addition, antioxidant enzymes such as superoxide dismutase, catalase and glutathione peroxidase cannot work independently and require mineral cofactors to work together. Therefore, they can supplement the mineral cofactors from food to improve the antioxidant capacity of antioxidant enzymes. In the non-enzymatic antioxidant system, common substances are ascorbic acid, tocopherol, β-carotene, flavonoid and polyphenol. Antioxidants usually cause antioxidation through the mechanism of scavenging free radicals, and are also called free radical scavengers. Common antioxidant evaluation methods include DPPH radical scavenging activity assay, ABTS radical scavenging activity assay, reducing power assay and so on.

3.1. Effects of Extract Solutions

The 50% inhibitory concentration (IC$_{50}$) indicates the concentration of the antioxidant required for the radical scavenging ability to reach 50%. The DPPH radical scavenging ability IC$_{50}$ values of ascorbic acid, BHT and Trolox, well-known antioxidant standards, are 8.35 µg/mL [31], 28.12 µg/mL [32] and 10.51 µg/mL [33], respectively. As indicated in Figure 2, the experimental IC$_{50}$ value of BHT was small, close to well-known antioxidant standards, and validated this assay. The jujube peel pulp extracted with 50% ethanol had the best DPPH scavenging ability (0.3 ± 0 mg/mL), followed by DI water (0.4 ± 0.1 mg/mL), 25% ethanol (0.4 ± 0.1 mg/mL), 75% ethanol (1 ± 0.1 mg/mL), and 95% ethanol (2.9 ± 0 mg/mL). This was in agreement with Delfanian et al. who mentioned that 50% ethanol extract was the best for DPPH radical scavenging ability [34]. These results are consistent with those of a previous study that reported that the best extraction condition was the use of 60.4% ethanol to extract jujube pulp at a temperature of 61.2 °C [35]. The same conclusion was also applied for banana [36] and pomegranate [37]. Therefore, in this study, we used 50% ethanol extraction in subsequent assays.
ABTS radical scavenging ability than the seeds did for both DI water and 50% ethanol extraction, corresponding to values ranging from 0.12 to 0.34 mg/mL for Boeun-deachu, Mechu, and Sanzoin cultivars [20]. The peel pulp with 50% ethanol exhibited better activity at 80 °C. Overall, the peel pulp had better ABTS radical scavenging activity at a temperature of 80 °C, whereas 50% ethanol exhibited better activity at 80 °C. The peel pulp or seeds extracted with 50% ethanol exhibited high DPPH radical scavenging activity at 80 °C. The peel pulp or seeds extracted with DI water exhibited high DPPH radical scavenging activity at 80 °C. Overall, the DPPH radical scavenging ability of peel pulp was better than seeds for both DI water and 50% ethanol extraction. Furthermore, the DPPH scavenging ability of peel pulp with 50% ethanol was better than that with DI water. The peel pulp with 50% ethanol at 60 °C exhibited the best scavenging ability (0.3 ± 0 mg/mL) among these test conditions and was close to other reported values ranging from 0.12 to 0.34 mg/mL for Boeun-deachu, Mechu, and Sanzoin cultivars [20].

3.2. DPPH Radical Scavenging Activity

The assessment of DPPH, a stable free radical molecule, radical scavenging activity is a common method for evaluating the ability to retard oxidative stress due to free radicals. As depicted in Figure 3, the peel pulp or seeds extracted with DI water exhibited high DPPH radical scavenging activity at 80 °C. The peel pulp or seeds extracted with 50% ethanol exhibited high DPPH radical scavenging activity at 60 °C. Overall, the DPPH radical scavenging ability of peel pulp was better than seeds for both DI water and 50% ethanol extraction. Furthermore, the DPPH scavenging ability of peel pulp with 50% ethanol was better than that with DI water. The peel pulp with 50% ethanol at 60 °C exhibited the best scavenging ability (0.3 ± 0 mg/mL) among these test conditions and was close to other reported values ranging from 0.12 to 0.34 mg/mL for Boeun-deachu, Mechu, and Sanzoin cultivars [20].

3.3. ABTS Radical Scavenging Activity

The ABTS radical scavenging ability IC50 values of well-known BHT and Trolox are 1.3 μg/mL and 2 μg/mL, respectively [38]. Figure 4 displays the results of the ABTS radical scavenging activity and the low experimental IC50 value of Trolox validates this assay. Peel pulp extracted with DI water exhibited better ABTS radical scavenging activity at a temperature of 80 °C, whereas 50% ethanol exhibited better activity at 60 °C. The seeds extracted with DI water exhibited better activity at 60 °C, and that extracted with 50% ethanol exhibited better activity at 80 °C. Overall, the peel pulp had better ABTS radical scavenging ability than the seeds did for both DI water and 50% ethanol extraction, corresponding to the result of DPPH radical scavenging activity in Figure 3. The peel pulp and seeds
extracted with 50% ethanol had better radical scavenging ability than did those extracted with DI water. Among all of the tested conditions, peel pulp extraction with 50% ethanol at 60 °C demonstrated the best scavenging ability (0.5 ± 0 mg/mL).

![Graph showing ABTS IC₅₀ values](https://via.placeholder.com/150)

**Figure 4.** ABTS IC₅₀ of jujube peel pulp and seeds extracted with DI water and 50% ethanol at different temperatures. The error bar represents the standard error of the mean. The temperatures in the histogram with the same letter were not significantly different at the 5% level, according to the results of the LSD test.

### 3.4. Total Phenolic Content

Jujube fruit is rich in polyphenols. Figure 5 reveals that the peel pulp extracted with DI water had the highest total phenolic content at 60 °C, and that extracted with 50% ethanol at 40, 60, and 80 °C had similar total phenolic content. The seeds extracted with DI water had the highest total phenolic content at 80 °C, and those extracted with 50% ethanol had similar total phenolic content at 60 and 80 °C. The total phenolic content of peel pulp extracted with 50% ethanol at 60 °C was 38.3 ± 0.4 mg GAE/g DW, and that extracted with 50% ethanol at 80 °C was 39.6 ± 2.3 mg GAE/g DW. The total phenolic content of peel pulp was also higher than that extracted with 95% ethanol at room temperature, ranging from 0.45 to 12.99 mg GAE/g DW for different cultivars [19]. The total phenolic content of peel pulp was also higher than the optimized extraction condition of ethanol concentration, temperature and time in the report of Han et al. [35]. Compared to the results in Figures 3 and 4, the total phenolic content showed a negative correlation with the IC₅₀ values of DPPH radical scavenging activity and ABTS radical scavenging activity. According to the literature [14,19,39], the possible phenolic compounds present in jujube fruit include caffeic acid, catechin, chlorogenic acid, ellagic acid, epicatechin, ferulic acid, gallic acid, p-coumaric acid, phlorizin, p-hydroxybenzoic acid, protocatechuic acid, rosmarinic acid, and rutin.

![Graph showing total phenolic content of jujube peel pulp and seeds](https://via.placeholder.com/150)

**Figure 5.** Total phenolic content of jujube peel pulp and seeds extracted with DI water and 50% ethanol at different temperatures. The error bar represents the standard error of the mean. Temperatures in the histogram with the same letter were not significantly different at the 5% level, according to the results of the LSD test.
3.5. Total Flavonoid Content

Determining the total flavonoid content is a crucial method for identifying favorable materials for Chinese medicine. As depicted in Figure 6, the peel pulp extracted with DI water had the highest total flavonoid content at 80 °C, and that extracted with 50% ethanol had the highest total flavonoid content at 60 °C. The flavonoid content extracted from seeds with DI water or 50% ethanol was highest at a temperature of 60 °C. The total flavonoid content of peel pulp and seeds was higher when extracted with 50% ethanol than with DI water, and that of peel pulp was higher than that of seeds. The peel pulp extracted in 50% ethanol at a temperature of 60 °C had the highest total flavonoid content (43.8 ± 0.2 mg QE/g DW). The total flavonoid content of peel pulp extracted with 50% ethanol was higher than the highest ever total flavonoid content (27.4 mg QE/g DW), extracted with chloroform, reported for jujube fruit [40]. According to the literature [12,20], the flavonoids possibly present in pulp are epicatechin, kaempferol-glucosyl-rhamnoside, procyanidin B2, quercetin-3-O-galactoside, and quercetin-3-O-rutinoside. The possible flavonoids in seeds are 6′′′-feruloylspinosin, 6′′′-hydroxybenzoylspinosin, saponarin, spinosin, swertish, and vitexin.

![Figure 6](image_url)

**Figure 6.** Total flavonoid content of jujube peel pulp and seeds extracted with DI water and 50% ethanol at different temperatures. The error bar represents the standard error of the mean. The temperatures in the histogram with the same letter were not significantly different at the 5% level, according to the results of the LSD test.

3.6. Reducing Power

In this study, the ferric reducing power is related to a compound’s electron transfer ability and presents the indicator of its antioxidant activity. Figure 7 displays the result of the assay in reducing power, similar to the result of the total flavonoid content in Figure 6. Peel pulp extracted using DI water or 50% ethanol exhibited the best reducing power (41.9 ± 2.2 mg AAE/g DW) at the temperature of 60 °C. Measurement of the reducing power of the seeds extracted with DI water was difficult, and the seeds extracted with 50% ethanol had the best reducing power at 60 °C. The reducing power of peel pulp and seeds extracted with 50% ethanol was better than that of DI water, and that of peel pulp was better than that of seeds. Compared to the literature, the reducing power of peel pulp extracted with 50% ethanol in this study is higher than extracted with 70% ethanol in 20 varieties of Chinese jujube [41].

In this study, the results of five antioxidant models, DPPH radical scavenging activity, ABTS radical scavenging activity, total phenolic content, total flavonoid content, and reducing power indicated that peel pulp exhibited better antioxidant capacity than did seeds. A similar trend was also shown by investigation of *Canarium odontophyllum* Miq. [42] and *Punica granatum* L. fruit [43].

Besides jujube, famous plants with antioxidant activity in Miaoli include black tea leaves [44] and *Jatropha curcas* L. [31]. They show the same finding as jujube fruit and *Jatropha curcas* L. seeds that extracts by ethanol solution have better antioxidant activity than extracts by DI water. The DPPH scavenging activity, total phenolic content, and reducing power of peel pulp of jujube are close to that of seed kernel of *Jatropha curcas* L. The total phenolic content of jujube peel pulp is also nearly that of...
black tea steeped at 60 °C. The higher extraction yield of jujube peel pulp compared to black tea leaves and Jatropha curcas L. seeds benefits jujube fruit for applications.

**Figure 7.** Reducing power of jujube peel pulp and seeds extracted with DI water and 50% ethanol at different temperatures. The error bar represents the standard error of the mean. The temperatures in the histogram with the same letter were not significantly different at the 5% level, according to the LSD test.

4. Conclusions

To understand the best condition of Miaoli jujube fruit for applications, this study investigated the effects of different fruit parts and extraction conditions on the antioxidant capacity. The results indicate that peel pulp has a greater antioxidant capacity than seeds. Peel pulp extracted with 50% ethanol at a temperature of 60 °C had the best antioxidant capacity in terms of DPPH radical scavenging ability, ABTS radical scavenging ability, total flavonoid content, and reducing power. Peel pulp extracted using 50% ethanol at 80 °C had the best total phenol content. The results in this study can be useful for selecting a potential source of natural antioxidants for food applications, benefiting intake of health promoting compounds and prevention of chronic diseases.

**Author Contributions:** Conceptualization, Y.-S.L.; methodology and formal analysis, W.-S.L. and M.-Y.C.; data curation, J.-W.T.; Y.-C.C. and C.-Y.C.; writing—original draft preparation, Y.-S.L.; writing—review and editing, Y.-S.L. and S.-L.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by National United University (NUU109LSP004) and the Ministry of Science and Technology, Taiwan.

**Conflicts of Interest:** The authors have no conflicts of interest to declare. The funding sponsor played no role in the design of the study; collection, analyses, or interpretation of data; writing of the manuscript; or decision to publish the results.

**References**

1. Zhang, H.; Jiang, L.; Ye, S.; Ye, Y.; Ren, F. Systematic evaluation of antioxidant capacities of the ethanolic extract of different tissues of jujube (Ziziphus jujuba Mill.) from China. *Food Chem. Toxicol.* **2010**, *48*, 1461–1465. [CrossRef] [PubMed]
2. Reche, J.; Hernández, F.; Almansa, M.S.; Carbonell-Barrachina, Á.A.; Legua, P.; Amorós, A. Physicochemical and nutritional composition, volatile profile and antioxidant activity differences in Spanish jujube fruits. *LWT-Food Sci. Technol.* **2018**, *98*, 1–8. [CrossRef]
3. Gao, Q.H.; Wu, C.S.; Wang, M. The jujube (Ziziphus jujuba Mill.) fruit: A review of current knowledge of fruit composition and health benefits. *J. Agric. Food Chem.* **2013**, *61*, 3351–3363. [CrossRef] [PubMed]
4. Wojdylo, A.; Figiel, A.; Legua, P.; Lech, K.; Carbonell-Barrachina, Á.A.; Hernández, F. Chemical composition, antioxidant capacity, and sensory quality of dried jujube fruits as affected by cultivar and drying method. *Food Chem.* **2016**, *207*, 170–179. [CrossRef] [PubMed]
5. Plastina, P.; Bonofiglio, D.; Vizza, D.; Fazio, A.; Ravito, D.; Giordano, C.; Barone, I.; Catalano, S.; Gabriele, B. Identification of bioactive constituents of Ziziphus jujuba fruit extracts exerting antiproliferative and apoptotic effects in human breast cancer cells. J. Ethnopharmacol. 2012, 140, 325–332. [CrossRef] [PubMed]

6. Siriamornpun, S.; Weerapreeyakul, N.; Barusrux, S. Bioactive compounds and health implications are better for green jujube fruit than for ripe fruit. J. Funct. Food 2015, 12, 246–255. [CrossRef]

7. Ji, X.; Peng, Q.; Yuan, Y.; Shen, J.; Xie, X.; Wang, M. Isolation, structures and bioactivities of the polysaccharides from jujube fruit (Ziziphus jujuba Mill.): A review. Food Chem. 2017, 227, 349–357. [CrossRef]

8. Hossain, M.A. A phytopharmacological review on the Omani medicinal plant: Ziziphus jujube. J. King Saud Univ. Sci. 2019, 31, 1352–1357. [CrossRef]

9. Ji, X.; Zhang, F.; Zhang, R.; Liu, F.; Peng, Q.; Wang, M. An acidic polysaccharide from Ziziphus jujuba cv. Muzao: Purification and structural characterization. Food Chem. 2019, 274, 494–499. [CrossRef] [PubMed]

10. Wang, L.; Fu, H.; Wang, W.; Wang, Y.; Zheng, F.; Ni, H.; Chen, F. Analysis of reducing sugars, organic acids and minerals in 15 cultivars of jujube (Ziziphus jujuba Mill.) fruits in China. J. Food Compos. Anal. 2018, 73, 10–16. [CrossRef]

11. Song, J.; Bi, J.; Chen, Q.; Wu, X.; Lyu, Y.; Meng, X. Assessment of sugar content, fatty acids, free amino acids, and volatile profiles in jujube fruits at different ripening stages. Food Chem. 2019, 270, 344–352. [CrossRef] [PubMed]

12. Du, L.J.; Gao, Q.H.; Ji, X.L.; Ma, Y.J.; Xu, F.Y.; Wang, M. Comparison of flavonoids, phenolic acids, and antioxidant activity of explosion-puffed and sun-dried jujubes (Ziziphus jujuba Mill.). J. Agric. Food Chem. 2013, 61, 11840–11847. [CrossRef] [PubMed]

13. Kou, X.; Chen, Q.; Li, X.; Li, M.; Kan, C.; Chen, B.; Zhang, Y.; Xue, Z. Quantitative assessment of bioactive compounds and the antioxidant activity of 15 jujube cultivars. Food Chem. 2015, 173, 1037–1044. [CrossRef] [PubMed]

14. San, B.; Yıldırım, A.N. Phenolic, alpha-tocopherol, beta-carotene and fatty acid composition of four promising jujube (Ziziphus jujuba Miller) selections. J. Food Compos. Anal. 2010, 23, 706–710. [CrossRef]

15. Guo, J.; Yan, Y.; Wang, M.; Wu, Y.; Liu, S.Q.; Chen, D.; Lu, Y. Effects of enzymatic hydrolysis on the chemical constituents in jujube alcoholic beverage fermented with Torulaspora delbrueckii. LWT-Food Sci. Technol. 2018, 97, 617–623. [CrossRef]

16. Ji, X.; Peng, Q.; Yuan, Y.; Liu, F.; Wang, M. Extraction and physicochemical properties of polysaccharides from Ziziphus jujuba cv. Muzao by ultrasound-assisted aqueous two-phase extraction. Int. J. Biol. Macromol. 2018, 108, 541–549. [CrossRef]

17. Liu, X.X.; Liu, H.M.; Yan, Y.Y.; Fan, L.Y.; Yang, J.N.; Wang, X.D.; Qin, G.Y. Structural characterization and antioxidant activity of polysaccharides extracted from jujube using subcritical water. LWT-Food Sci. Technol. 2020, 117, 108645. [CrossRef]

18. Wu, C.S.; Gao, Q.H.; Guo, X.D.; Yu, J.G.; Wang, M. Effect of ripening stage on physicochemical properties and antioxidant profiles of a promising table fruit ‘pear-jujube’(Zizyphus jujuba Mill.). Sci. Hortic. 2012, 148, 177–184. [CrossRef]

19. Zhao, H.X.; Zhang, H.S.; Yang, S.F. Phenolic compounds and its antioxidant activities in ethanolic extracts from seven cultivars of Chinese jujube. Food Sci. Hum. Wellness 2014, 3, 183–190. [CrossRef]

20. Choi, S.H.; Ahn, J.B.; Kozukue, N.; Levin, C.E.; Friedman, M. Distribution of free amino acids, flavonoids, total phenolics, and antioxidative activities of jujube (Ziziphus jujuba) fruits and seeds harvested from plants grown in Korea. J. Agric. Food Chem. 2011, 59, 6594–6604. [CrossRef]

21. Kao, T.H.; Chen, B.H. Functional components in Zizyphus with emphasis on polysaccharides. In Polysaccharides: Bioactivity and Biotechnology; Ramawat, K.G., Mériton, J.M., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2015; pp. 795–827.

22. Wojdyło, A.; Carbonell-Barrachina, Á.A.; Legua, P.; Hernández, F. Phenolic composition, ascorbic acid content, and antioxidant capacity of Spanish jujube (Ziziphus jujuba Mill.) fruits. Food Chem. 2016, 201, 307–314. [CrossRef] [PubMed]

23. Koley, T.K.; Kaur, C.; Nagal, S.; Walia, S.; Jaggi, S. Antioxidant activity and phenolic content in genotypes of Indian jujube (Ziziphus mauritiana Lamk.). Arab. J. Chem. 2016, 9, S1044–S1052. [CrossRef]

24. Chang, S.C.; Hsu, B.Y.; Chen, B.H. Structural characterization of polysaccharides from Ziziphus jujuba and evaluation of antioxidant activity. Int. J. Biol. Macromol. 2010, 47, 445–453. [CrossRef] [PubMed]
25. Gao, Q.H.; Wu, P.T.; Liu, J.R.; Wu, C.S.; Parry, J.W.; Wang, M. Physico-chemical properties and antioxidant capacity of different jujube (Ziziphus jujuba Mill.) cultivars grown in loess plateau of China. Sci. Hortic. 2011, 130, 67–72. [CrossRef]

26. Tsai, C.C.; Chan, C.F.; Huang, W.Y.; Lin, J.S.; Chan, P.; Liu, H.Y.; Lin, Y.S. Applications of Lactobacillus rhamnosus spent culture supernatant in cosmetic antioxidation, whitening and moisture retention applications. Molecules 2013, 18, 14161–14171. [CrossRef]

27. Huang, W.Y.; Lee, P.C.; Hsu, J.C.; Lin, Y.R.; Chen, H.J.; Lin, Y.S. Effects of water quality on dissolution of yerba mate extract powders. Sci. World J. 2014, 2014, 768742. [CrossRef]

28. Huang, W.Y.; Lin, Y.R.; Ho, R.F.; Liu, H.Y.; Lin, Y.S. Effects of water solutions on extracting green tea leaves. Sci. World J. 2013, 2013, 368350. [CrossRef]

29. Chan, C.F.; Wu, C.T.; Huang, W.Y.; Lin, W.S.; Wu, H.W.; Huang, T.K.; Chang, M.Y.; Lin, Y.S. Antioxidation and melanogenesis inhibition of various Dendrobium tosaense extracts. Molecules 2018, 23, 1810. [CrossRef]

30. Wu, C.T.; Agrawa, D.C.; Huang, W.Y.; Hsu, H.C.; Yang, S.J.; Huang, S.L.; Lin, Y.S. Functionality analysis of spent coffee ground extracts obtained by the hydrothermal method. J. Chem. 2019, 2019, 4671438. [CrossRef]

31. Huang, S.L.; Wang, W.H.; Zhong, X.Y.; Lin, C.T.; Lin, W.S.; Chang, M.Y.; Lin, Y.S. Antioxidant properties of Jatropha curcas L. seed shell and kernel extracts. Appl. Sci. 2020, 10, 3279. [CrossRef]

32. Rajopadhye, A.; Upadhye, A.S. Estimation of bioactive compound, maslinic acid by HPTLC, and evaluation of hepatoprotective activity on fruit pulp of Ziziphus jujuba Mill. cultivars in India. Evid.-Based Complement Altern. Med. 2016, 2016, 4758734. [CrossRef] [PubMed]

33. Nakajima, Y.; Sato, Y.; Konishi, T. Antioxidant small phenolic ingredients in Inonotus obliquus (persoon) Pilat (Chaga). Chem. Pharm. Bull. 2007, 55, 1222–1226. [CrossRef] [PubMed]

34. Delfanian, M.; Esmaeilzadeh Kenari, R.; Sahari, M.A. Utilization of Jujube fruit (Ziziphus mauritiana Lam.) extracts as natural antioxidants in stability of frying oil. Int. J. Food Prop. 2016, 19, 789–801. [CrossRef]

35. Han, H.J.; Lee, J.S.; Park, S.A.; Ahn, J.B.; Lee, H.G. Extraction optimization and nanoencapsulation of jujube (Ziziphus jujuba Mill.) peel antioxidants by response surface methodology. Molecules 2018, 23, 3279. [CrossRef]

36. González-Montelongo, R.; Gloria Lobo, M.; González, M. Antioxidant activity in banana peel extracts: Testing extraction conditions and related bioactive compounds. Food Chem. 2010, 119, 1030–1039. [CrossRef]

37. Tabarak, R.; Heidarizadi, E.; Benvidi, A. Optimization of ultrasonic-assisted extraction of pomegranate (Punica granatum L.) peel antioxidants by response surface methodology. Sep. Purif. Technol. 2012, 98, 16–23. [CrossRef]

38. Li, X.; Han, W.; Mai, W.; Wang, L. Antioxidant activity and mechanism of tetrahydroamomentoflavone in vitro. Nat. Prod. Commun. 2013, 8, 787–789. [CrossRef]

39. Wang, B.; Huang, Q.; Venkitasamy, C.; Chai, H.; Gao, H.; Cheng, N.; Cao, W.; Lv, X.; Pan, Z. Changes in phenolic compounds and their antioxidant capacities in jujube (Ziziphus jujuba Miller) during three edible maturity stages. LWT-Food Sci. Technol. 2016, 66, 56–62. [CrossRef]

40. Al-Saeedi, A.H.; Al-Ghafri, M.T.H.; Hussain, M.A. Comparative evaluation of total phenols, flavonoids content and antioxidant potential of leaf and fruit extracts of Omani Ziziphus jujuba L. Pac. Sci. Rev. A Nat. Sci. Eng. 2016, 18, 78–83. [CrossRef]

41. Zhang, Z.; Gao, W.; Yan, Y.; Huang, L. Study on the relationship between chemical compositions and antioxidative activity of Ziziphus jujuba Mill. by chemometric approach. Int. J. Food Prop. 2015, 18, 277–289. [CrossRef]

42. Prasad, K.N.; Chew, L.Y.; Khoo, H.E.; Kong, K.W.; Azlan, A.; Ismail, A. Antioxidant capacities of peel, pulp, and seed fractions of Canarium odontophyllum Miq. fruit. J. Biomed. Biotechnol. 2010, 2010, 871379. [CrossRef] [PubMed]

43. Elfalleh, W.; Hannachi, H.; Tlili, N.; Yahia, Y.; Nasri, N.; Ferchichi, A. Total phenolic contents and antioxidant activities of pomegranate peel, seed, leaf and flower. J. Med. Plants Res. 2012, 6, 4724–4730. [CrossRef]

44. Chang, M.Y.; Lin, Y.Y.; Chang, Y.C.; Huang, W.Y.; Lin, W.S.; Chen, C.Y.; Huang, S.L.; Lin, Y.S. Effects of infusion and storage on antioxidant activity and total phenolic content of black tea. Appl. Sci. 2020, 10, 2685. [CrossRef]