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Nutrient Composition, Antioxidant Activities and Anti-Inflammatory Effect of Jujube Fruit: A General Review

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Abstract:

Jujube (*Ziziphus jujuba*) fruit belongs to the *Rhamnaceous* family and is widely located in the tropical and subtropical regions of Asia as well as in the Mediterranean regions including Jordan. Therefore, the aim of this review was to illustrate the nutritional value of jujube fruit and its importance in human health protection as antioxidant and anti-inflammatory agent. Recently, several scientific reports have been carried out about the presence of many biologically active compounds from *Z. jujuba*, which may have high potential benefit in human nutrition, health, and disease. Based on previous studies, jujube fruit can possess good antioxidant and anti-inflammatory activity rendering it a functional food. Since jujube fruit has diverse biological activity, further biological studies including clinical-based studies are recommended to explore the health promoting effect of jujube.

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INTRODUCTION

Oxidation is essential to many living organisms for producing energy to fuel biological processes. However, oxygen-derived free radicals resulting from uncontrolled production have many adverse effects to the body. It can damage the cells and their functions, and thus play an important role in pathogenesis of some diseases, such as cancer, cardiovascular diseases, atherosclerosis and inflammation [1]. Naturally occurring antioxidants have received a great deal of attention because they are able to prevent oxidative damage induced by free radicals and are safer than synthetic antioxidants [2]. The association between the consumption of fruits and vegetables and decreased risk of heart diseases and cancer is established by many researches [3-5].

Fruits and vegetables are good sources of phytochemicals. Fruits contain various antioxidants such as phenolics, carotenoids and vitamins, which are considered to be responsible for the health benefits and for decreasing the risk of diseases caused by oxidative stress and macromolecular oxidation [6-8]. Thus, interest in the investigation of biological activities and bioactive compounds of fruits and vegetables has increased significantly in recent years [9].

Jujube (*Zizyphus jujuba*) or *Innab*, belongs to the *Rhamnaceae* family and is one of the most important *Zizyphus* species. *Z. jujuba* is widely located in the tropical and subtropical regions of Asia as well as in the Mediterranean regions including Jordan [10]. Jujube is a medium/large deciduous tree and its fruits are oval in shape. Unripe jujube fruits are green and smooth, but when ripe fruit turns red or brown and eventually wrinkled, looking like a small date [11]. The fruit is the edible and nutritive part of the plant and is consumed as a source of food. Jujube fruit is rich in nutrients, including sugars, amino acids, fiber, and minerals such as potassium, calcium, magnesium, and iron [12, 13]. Jujube is a seasonal fruit and deteriorates rapidly after harvesting; therefore, it is typically dried for storage [11].

Recently, several scientific reports have been carried out about the presence of many biologically active compounds from *Z. jujuba*, which may have high potential benefits in human nutrition, health, and disease [13-15]. The high antioxidant activity of the extracts from different parts of jujube fruit such as peel, pulp, and seeds has been reported [14,16,17]. This antioxidant activity has been attributed to the high level

of phenolic compounds. The phenolic compounds can inhibit radical chain reactions or decrease singlet oxygen level in oxidation reactions; they also have roles in diseases- risk reduction and health promotion [18]. In addition, various studies have shown that jujube fruit has anti-inflammatory activities that are attributed to their high content of triterpenic acids [19].

Therefore, the aim of this review is to illustrate the nutritional value of jujube fruit and the importance of jujube in human health protection as antioxidant and anti-inflammatory agent.

NUTRIENT COMPOSITION OF JUJUBE FRUIT

Jujube has a high nutritional value due to the presence of large amount of nutrients and phytochemicals, such as fibers, proteins, carbohydrate, fat, vitamins (ascorbic acid, riboflavin, and thiamin) and minerals [13,20,21]. Sucrose, fructose and glucose are the major sugars found in the fruit that contribute to its sweetness [22]. Although the protein content of jujube is low, it contains eighteen amino acids including eight essential amino acids [23]. In addition, the lipid content of the fresh fruit is very low. The main fatty acids are oleic acid, linoleic acid, palmitic acid and palmitoleic acid. Moreover jujube fruit is rich in phenolic compounds such as catechin and rutin which play an important roles in affecting the nutritional properties of the fruit [24].

Macronutrients

Several studies were conducted to evaluate macronutrients in jujube fruit. These studies confirmed that jujube fruits have large amounts of macronutrients and the contents were varied depending on its location, cultivars and maturity stage (Table 1).

For example, a study conducted on four cultivars of *Zizyphus jujube* Mill (GAL, MSI, PSI and DAT) in Spain showed variation in sugar, protein and fibre contents among the cultivars. The total sugars ranged from 10.8 to 19.2 (g / 100 mL) with the highest total sugars content was found in MSI fruits, while the lowest one was observed in PSI. Whereas the protein content of jujube fruits ranged between 3.7% DW in 'DAT' fruits and 5.8% DW in 'PSI' and the crude fiber ranged from 0.7 to 1.0 g/ 100 of dry weight. The moisture of jujube fruits ranged from 78.3% to 82.1%. The fruits of 'PSI' and 'GAL' showed the highest moisture content, while 'DAT' had the lowest one. The study revealed the variation in chemical contents among the cultivars to

Table 1: Nutrition Contents of *Ziziphus jujuba* According to its Location, Cultivar and Fruit Maturity

Author and year	Location	Cultivars	Fruit maturity	Nutrient Composition
Chen <i>et al.</i> , 2019	Hami district, China	<i>Zizyphus jujube</i> cv. Dazao	Mature	MC 68.5 g/100g; TDF 7.32g/100g; Protein 3.97g/100g; Ash 1.05g/100g; TS 30%; ascorbic acid 185.5mg/100g.
	Hami district, China	<i>Ziziphus jujuba</i> cv. Junzao	Mature	MC 67.5 g/100g; TDF 5.0g/100g; Protein 1.87 g/100g; Ash 1.1 g/100g; TS (%) 29%; ascorbic acid 221.1 mg/100g.
	Akesu district, China	<i>Ziziphus jujuba</i> cv. Huizao	Mature	MC 63.6 g/100g; TDF 5.6g/100g; Protein 2.5g/100g; Ash 1.03g/100g; TS (%) 32%; ascorbic acid 182.6 mg/100g.
Choi <i>et al.</i> , 2011	Korea	<i>Ziziphus jujuba</i> Mill	Red maturity	W.C 86.4%; FAA 243.2 mg/100g;
Song <i>et al.</i> , 2019	Akesu, China	<i>Zizyphus jujuba</i> cv. Junzao	-Green maturity	W.C 6.1 g/g DW; T.S 616 mg/g; FAA 2908.4 mg/100g
			-Yellow maturity	W.C 4.3 g/g DW; T.S 678 mg/g; FAA 2803.9 mg/100g
			-Half-red maturity	W.C 3.5 g/g DW; T.S 709.4 mg/g; FAA 2072.7 mg/100g
			- Red maturity	W.C 3.1 g/ g DW; T.S 771.3 mg/g; FAA 2532.2 mg/100g
Wang <i>et al.</i> , 2018	Shanxi province, China	15 cultivars of <i>Ziziphus jujuba</i> Mill	-	Glucose (85.9–1005 mg/100 g FW), iron (5.27–12.5 mg/100 g DW), calcium (16.2–30.2 mg/100 g DW) and magnesium (51.2–70.0 mg/100 g DW)
Hernandez <i>et al.</i> , 2016	Spain	4 cultivars of <i>Ziziphus jujuba</i> Mill	Mature	TS 10.8-19.2 g/100ml, Protein 3.7-5.0 % DW, crude fiber 0.7 -1.0g/100g DW, potassium 11.9-17.3 g/Kg DW, calcium 0.23-0.72 g/kg DW, Magnesium 0.40-0.77 g/kg Dw, sodium 0.11-0.43 g/kg DW; Iron 10.2-17.1 mg/kg; zinc 4.0-5.1 mg/kg; copper 0.5-1.2 mg/kg, manganese 0.2-2.9 mg/kg;
Li <i>et al.</i> , 2007	China	<i>Zizyphus jujuba</i> cv. Jinsixiaozao, <i>Zizyphus jujuba</i> cv. Jianzao, <i>Zizyphus jujuba</i> cv. Yazao, <i>Zizyphus jujuba</i> cv. Junzao <i>Zizyphus jujuba</i> cv. Sanbianhong.	-	Carbohydrate 80.9–85.6% ;protein 4.75–6.86%, Lipid 0.37–1.02%; moisture 17.38–22.52%; ash 2.26–3.01%; soluble fiber 0.57–2.79%; insoluble fiber 5.24–7.18%; vitamin C 192-359 mg/100g, thiamine 0.04-0.08 mg/100g, riboflavin 0.05-0.09 mg/100g; potassium contents 79.2- 458 mg/100g; phosphorus 59.3 -110 mg/100g, calcium 45.6 – 118 mg/100g , manganese 24.6 -51.2 mg/100g, iron 4.7 -7.9 mg/100g, sodium 3.2 -7.6mg/100g, zinc 0.35 to 0.63 mg/100g, and copper 0.19- 0.42 mg/100g
Alghadban <i>et al.</i> , 2021	Rif Damascus-southwestern Syria	<i>Ziziphus jujuba</i> cv. Junzao	Mature	Moisture 16.1%, Fat 0.46%, Fiber 6.0%, Ash 1.8%, protein 4.8%, carbohydrate % 60.7; potassium; 201 mg/100 g; phosphorus 72.9 mg/100g; calcium 65.8 mg/100g; manganese 34.6 mg/100g; Iron 9.2 mg/100g, sodium 5.9 mg/100g; zinc 0.42 mg/100g, Copper 0.19 mg/100g.
	Latakia - northwestern Syria.	<i>Ziziphus jujuba</i> cv. yazao.	Mature	Moisture 20.9%, Fat 0.6%, Fiber 9.6%, Ash 2.8%, protein 7.2%, carbohydrate % 51.0; potassium 179.1 mg/100g; phosphorus 103.6 mg/100g; calcium 91.9 mg/100g, manganese 40.1 mg/100g; Iron 7.7 mg/100g; sodium 7.6 mg/100g, zinc 0.26 mg/100g, copper 0.28 mg/100g

W.C water content; T.S total sugar; TDF total dietary fiber; FAA free amino acid; FW fresh weight; DW dry weight.

the genotype since all evaluated Spanish cultivars were grown under homogeneous conditions [24].

In another study, the proximate composition of five cultivars of Chinese jujube was determined.

Investigations showed that the carbohydrate contents of the five cultivars of Chinese jujube were similar and ranged from 80.9 (*Zizyphus jujube* cv. Yazao) to 85.6% (*Zizyphus jujube* cv. Sanbianhong). No significant difference existed in the carbohydrate contents among the five cultivars. On the other hand, the data showed significant differences among cultivars according to their contents of protein and ash. The protein contents of the five cultivars varied from 4.8 to 6.9% and ash contents varied from 2.3-3.0%. The five cultivars of Chinese jujube had lower lipid contents and their values ranged from 0.37 to 1.02% [25].

Song *et al.* [12] estimated sugar content, fatty acids, and free amino acids in Chinese Jujube fruits at different ripening stages. Four ripening stages were established: GM, green maturity; YM, yellow maturity; HRM, half-red maturity; RM, red maturity. The glucose and fructose showed the highest content of 228.6 mg/g and 277.8 mg/g in GM, respectively. Both glucose and fructose exhibited a downward trend during the ripening stage. This is because they mainly turn into polysaccharides and participate in some physical and chemical reactions. Sucrose and total sugar contents of jujube fruits showed an increasing tendency during ripening. The content of sucrose in RM (403.3mg/g) was almost 9 times that in GM (45.4mg/g). The total sugar contents ranged from 616.5mg/g (GM) to 771.3mg/g (RM) resulting in an increasing sweet taste of jujube fruits during ripening.

Another study was performed on three Chinese jujubes cultivated from different regions in China to investigate their physical and chemical composition. Results showed that the Junzao cultivar contained a relatively low level of the total dietary fiber, protein, total sugar, and total titratable acids. Whereas, Dazao cultivar showed a high level of total dietary fiber, protein and sugar. The study concluded that cultivation districts exerted important roles in altering the physicochemical indexes of the same jujube cultivar. The moisture content, total dietary fiber, protein, and total sugar of jujube fruit were ranged from 64.31 – 76.50, 4.85–7.32, 1.87–3.97 g/100 g and 28.68 to 31.7% on a fresh matter basis [20].

Recently, a study conducted on two cultivars of *Zizyphus jujuba* in two different regions in Syria revealed that both cultivars have a high nutritional value, but showed significant differences in the nutritional composition. The differences are attributed to the variation in the studied cultivar, fruit location, soil type, and its farming conditions (like climate, air

temperature, sunshine and precipitation rate), where the climate of Latakia district is characterized by high humidity and high precipitation rate in comparison with the climate of Rif Damascus district which is characterized by drought. The total protein content in *Zizyphus jujuba* cv. yazao (7.2%) which was harvested from Latakia was about 1.59 times larger than that in *Zizyphus jujuba* cv. Junzao (4.8%). Whereas, *Zizyphus jujuba* cv. Junzao showed about 1.18 times larger content of carbohydrates (60.7%) in comparison with *Zizyphus jujuba* cv. yazao (51.0%). The total fat and dietary fiber in both cultivars of *Zizyphus jujuba* were in the range of 0.46- 0.6 % and 6.0 -9.6% respectively [26].

Micronutrients

Micronutrients are vital elements for healthy growth and development as well as disease prevention. Previous studies indicated that jujube fruits were a rich source of micronutrients including vitamins and minerals [20, 27, 24]. Li *et al.* [25] evaluated the range of micronutrients in the five Chinese jujube cultivars including *Zizyphus jujuba* cv. Jinsixiaozao, *Zizyphus jujuba* cv. Jianzao, *Zizyphus jujuba* cv. Yazao, *Zizyphus jujuba* cv. Junzao, *Zizyphus jujuba* cv. Sanbianhong. The amounts of thiamine (0.04–0.08 mg/100 g), and riboflavin (0.05–0.09 mg/100 g) were low in the five cultivars. Whereas large amounts of vitamin C (192-359 mg/100g) were present. Based on their study, the range of minerals contents (mg/100 g FW) in jujube cultivars were as follows, potassium contents 79.2 to 458, phosphorus 59.3 to 110, calcium 45.6 to 118, manganese 24.6 to 51.2, iron 4.68 to 7.90, sodium 3.22 to 7.61, zinc 0.35 to 0.63, and copper 0.19 to 0.42. The variation in the mineral contents among cultivars may be contributed to climate, soil nutrient content, time of harvest and landraces used.

The same results were also reported by Alghadban *et al.* [26]. Eight mineral elements (Ca, K, P, Na, Fe, Zn, Cu and Mn) were determined in two cultivars of Syrian jujube fruits. The results revealed that both cultivars have a high nutritional value, but showed significant differences in the nutritional composition. Potassium was the most abundant element in both cultivars of Syrian jujube fruits, followed by phosphorus, calcium, manganese, iron, sodium, zinc and copper, respectively. The content of free potassium ranged from 179.1 mg/100 g in *Zizyphus jujuba* cv. yazao to 201.0 mg/100 g in *Zizyphus jujuba* cv. Junzao. The variation of mineral contents was attributed to the variation in the studied cultivar and fruit location.

Regarding the high content of vitamin C, Zhang *et al.* [17] determined the ascorbic acid contents in different tissues of jujube fruit. Three jujube cultivars, *Z. jujuba* cv. Dongzao, *Z. jujuba* cv. Muzao and *Z. jujuba* cv. Hamidazao were collected at commercial maturity from Hebei, China. The results clearly indicated that the pulps of Dongzao contained the greatest concentration of ascorbic acid (534.94 mg/100 g DW). However, in contrast to Dongzao, ascorbic acid was not detected as high in the pulp of Hamidazao and Muzao. Although the reason for the distributing discrepancy of three jujube varieties is unclear, the researchers explained the lower ascorbic acid content found in Hamidazao and Muzao pulps as a result of sun-drying of these two cultivars. In addition, the study showed that the seed extracts contained a small amount of ascorbic acid in all three cultivars, especially the seeds of Dongzao which only contained 5.57 mg/100 g DW.

In the case of 4 Spanish jujube cultivars (*Ziziphus jujube* Mill), the range of vitamin C content was found to be 0.41–0.64 (g /100 mL), while the contents of macro-elements content such as potassium, calcium, magnesium, and sodium were ranged between 11.9–17.3, 0.23–0.72, 0.40–0.77, and 0.11–0.43 g /kg dry weight, respectively. Furthermore, the range of microelements content such as iron, zinc, copper, and manganese was 10.2–17.1, 4.0–5.1, 0.5–1.2, and 0.2–2.9 mg per kg DW respectively. Differences in mineral contents among different variables may be related to the different genotypes and growing conditions [21]. A similar result regarding vitamin C was also reported by Wojdylo *et al.* [28] who found that the ascorbic acid content of Spanish jujube (*Ziziphus jujuba* Mill.) fruits was very high and the values ranged between 387–555 mg/100g fresh weight.

Analysis of vitamin C content in three Chinese jujube cultivars (*Ziziphus jujuba* Mill.) cultivated from different regions in china showed that the content ranged from 162.50 to 244.58 mg/100 g FW [20]. The researchers attributed the variation in content to the different studied cultivars and their locations. In summary, it is confirmed that jujube fruit is a potential source of micronutrients especially vitamin C.

Bioactive Compounds

Jujube fruit is considered a great source of bioactive components, including polyphenols, triterpenic acids, polysaccharides, nucleosides, and nucleobases. This plant is thus recognized as one of the rich sources of functional ingredients [28, 21]. However, the bioactive

components have been shown to vary both with cultivar and with growing conditions (Table 2). For example, in the pulp of jujube fruit, total phenolic compounds ranged from 1.1 to 2.4 g/100 g DW, and flavonoids contents ranged from 0.7 to 1.8 g/100 g DW. Furthermore, the jujube fruits contain several flavonoid compounds, such as procyanidin B2, epicatechin, quercetin-3- O-rutinoside, quercetin-3-O-galactoside, kaempferol-glucosyl-rhamnoside [14]. A study conducted by Wojdylo *et al.* [28] reported that 25 polyphenolic compounds were available in four Spanish jujube cultivars and the total polyphenols content ranged from 1442 to 3432 mg/100 g (DW). According to their study, a total of 10 flavan-3-ols, 13 flavonols, 1 flavanone, and 1 dihydrochalcone were detected in the Spanish jujube. Flavan-3-ols, a major group of polyphenols in jujube represent around 92% of the total polyphenols content, whereas flavonols represent only around 8%.

Another study showed that seven phenolic compounds namely catechin, caffeic acid, epicatechin, ferulic acid, rutin, p-hydroxybenzoic acid and chlorogenic acid, were isolated from fruits of jujube selections. Catechin level ranged from 2.46 to 3.74 mg/100g, whereas, rutin level ranged from 0.88 to 3.60 mg/ 100 g [24].

In Omani jujube fruit, the total polyphenols and flavonoids content ranged from 16.93 to 187.51 mg/g and 0.29 to 27.43 µg/g, respectively [29]. The total phenolic contents in peel and pulp of the fruits of three Chinese jujube cultivars were also determined. The study showed that the total phenolic content in peel was five to six times higher than in the pulp of all cultivars [30]. In another study, the total phenolics and flavonoids contents among different varieties of Chinese jujube were ranged from 428.5 to 660.4 (mg GAE/ 100g FW) for phenolics and 159.3 and 230.3 (mg rutin eq./ 100 g FW) for flavonoids contents [16].

In a more recent study, it was found that the total phenolic content of peel pulp extracted with 50% ethanol at 60° C was 38.3 ± 0.4 mg GAE/g DW, whereas total flavonoid content was 43.8 ± 0.2 mg QE/ g DW [11].

Wang *et al.* [31] investigated the changes in total phenolic content, total flavonoid content and individual phenolic compound content in jujube during three edible maturity stages. The results showed that caffeic acid was most predominant in all detected phenolic compounds at the white maturity stage, while rutin dominated at half-red maturity and red maturity.

Table 2: Bioactive Compound Contents of *Ziziphus jujuba* According to its Location, Cultivar, and Maturity Stage

Author and year	Cultivars	Location	Fruit maturity	Content	Main Outcome
Al-Saeedi <i>et al.</i> , 2016	<i>Ziziphus jujuba</i> L	Sur, Sultanate of Oman	Ripe	Phenolic compound Flavonoids	TPC 64.9 (mg/g); TFC 0.29 µg/g
Wojdylo <i>et al.</i> , 2016	<i>Ziziphus jujube</i> Mill	Village of San Isidro, Spain	Optimum ripeness	-Phenolic compound A total of 25 phenolic compounds were identified and classified as -10 flavan-3-ols, 13 flavonols, 1 flavanone, and 1 dihydrochalcone. Ascorbic acid	1442-3432 mg/100g DW 387-555 mg/100g FW
Zhang <i>et al.</i> , 2010	<i>Ziziphus jujuba</i> Miller	China	Mature	Ascorbic acid	Peel 36.9- 46.8 mg/100g DW Pulp 32.5-534.9 mg/100g DW Seed 5.6-21.3 mg/100g DW
				Flavonoids	Peel 276.3-1851.9mg QE/100g DW Pulp 217.4-390.1 mg QE/100g DW Seed 158.1-328.2 mg QE/100g DW
				Phenolic compound: Chlorogenic acid	Peel 45.2-180.3 mg/kg DW Pulp 42.8-61.2 mg/kg DW Seed 20.7-28.4 mg/kg DW
				Gallic acid	Peel 47.5-200.6 mg/kg DW Pulp 44.6-70.1 mg/kg DW Seed 27.5-29.3 mg/kg DW
				Protocatechuic acid	Peel 57.5-239.8 mg/kg DW Pulp 56.9- 85.6 mg/kg DW Seed 37.3-55.9 mg/kg DW
				Caffeic acid	Peel 24.2- 130.3 mg/kg DW Pulp 17.5-35.7 mg/kg DW Seed 7.9- 16.9 mg/kg DW
Choi <i>et al.</i> , 2011	<i>Ziziphus jujuba</i> Miller	Korea	Red maturity	Phenolic compound Flavonoids Fruits contained the following flavonoids: procyanidin B2, epicatechin, quercetin-3-O-rutinoside (Q-3-R), quercetin-3-O-galactoside (Q-3-G), kaempferol-glucosyl-rhamnoside (K-G-R), and two unidentified compounds.	TPC 2.36 (g/100g) Flavonoids: (1,794 mg/100g)
Wang <i>et al.</i> , 2016	<i>Ziziphus jujuba</i> cv. Jishanbanzao	North China	-White maturity -Half white maturity -Red maturity	Phenolic compound Flavonoids	-TPC 864.73(mg/100g);TFC 1002.00 (mg/100g) -TPC 259.00 (mg/100g); TFC 956.39 mg/100g) -TPC 71.67 (mg/100g); TFC 167.45 (mg/100g)
Lin <i>et al.</i> , 2020	<i>Ziziphus jujuba</i> Mill	Miaoli, Taiwan	Ripe fruit	Phenolic compound Flavonoids	TPC of peel pulp extracted with 50% ethanol at 60 °C was (38.3 mg GAE/gram dry weight), Whereas TFC was(43.8 mg quercetin / gram dry weight), and reducing power (41.9 ± 2.2 mg ascorbic acid equivalent per gram dry weight).

(Table 2). Continued.

Author and year	Cultivars	Location	Fruit maturity	Content	Main Outcome
San and Yildirim., 2010	<i>Zisiphus jujuba</i> Mill	Turkey	Ripe fruit	Seven Phenolic compound: Catechin Caffeic acid Epicatechin Rutin <i>p</i> -Hydroxybenzoic acid Chlorogenic acid Alpha-tocopherol Beta-caotene	3.25-3.74 mg/100g FW 0.23- 0.57 mg/100g FW 0.19- 0.48 mg/100g FW 0.88-2.63 mg/100g FW 0.08-0.1 mg/100g FW 0.11-0.18 mg/100g FW 0.04-0.07 mg/100g FW 7.0-26.0 µg/100g FW

TPC Total phenolic content; TFC Total flavonoid content; FW fresh weight; DW Dry weight.

In addition, the phenolic contents and their activities greatly decreased with the increasing maturity stage. These results were consistent with the data reported by other studies [32,33,34,]. The rapid decrease of total phenolics is associated with the increase of total sugars content also indicates the high metabolic activity of jujubes for the biosynthesis of secondary metabolites from the white ripening stage [22].

Jujube contained a low amount of triterpenic acids, nucleosides, and nucleobases. A study by Guo *et al.* [35] reported that the triterpenic acids content in the jujube fruit (mg/100 g DW) was 222.33, and total nucleosides and nucleobases (µg/g DW) was 509.59. In the case of fresh jujube, the titratable acids content of 3 Chinese jujube cultivars ranged from 1.98 to 3.12% FW and total flavonoids ranged from 41.21 to 62.72 (mg/g FW) [20].

On the other hand, polysaccharides are one of the most abundant components of the *Z.jujuba* fruit and represent a major group of biologically active constituents [36].

Zhan *et al.* [37] found that the average molecular weight of polysaccharide (ZJP) in Chinese jujube fruit was 153.3 kDa, which consisted of galacturonic acid. Another study reported that the acidic polysaccharides in jujube fruit were mainly rhamnose, galactose, and galacturonic acid with a molecular weight of 9.37 kDa [38]. A recent study confirmed that the maximum crude polysaccharide yield obtained from jujube fruit was 7.9%. According to their research results, the main components of jujube polysaccharides were arabinose, galactose, glucose, mannose, rhamnose, and galacturonic acid [39].

Liu *et al.* [40] evaluated the composition of water extracts of *Ziziphus jujuba* cv. Jinsixiaozao. The results

showed that polysaccharides were found to be the most abundant compounds in the extracts. The contents of total phenolics, total flavonoids and polysaccharides were 143 mg gallic acid equivalent (GAE) per g of dry plant, 0.17 mg of rutin equivalent (RE) per g of dry plant, and 3.80 mg per g of dry plant, respectively. The main components of the phenolic acids were protocatechuic acid, catechol, *p*-hydroxybenzoic acid, vanilla and *p*-coumaric acid.

BIOLOGICAL ACTIVITY

Several studies reported that jujube fruits or extracts have diverse biological activities such as antioxidant and anti-inflammation which are due to the availability of many biological compounds mostly polyphenols. [11,40-42].

Polyphenols on Oxidative Stress

The antioxidant capacity of the jujube fruit is closely correlated to the presence of efficient oxygen radical scavengers, such as phenolic compounds [24,31,43].

Polyphenol antioxidant activity depends on the structure of their functional groups. The number of hydroxyl groups greatly influences several mechanisms of antioxidant activity such as scavenging radicals and metal ion chelation ability [44]. Polyphenols have been found to be strong antioxidants that can neutralize free radicals by donating an electron or hydrogen atom. The highly conjugated system and certain hydroxylation patterns such as the 3-hydroxy group in flavonols are considered important in the antioxidant activities. Polyphenols suppress the generation of free radicals, thus reducing the rate of oxidation by inhibiting the formation of or deactivating the active species and precursors of free radicals [45]. In addition to radical scavenging, polyphenols are also known as metal

chelators. Chelation of transition metals such as Fe^{2+} can directly reduce the rate of Fenton reaction, thus preventing oxidation caused by highly reactive hydroxyl radicals [46].

In addition, polyphenol antioxidant activities are related to their capacity to scavenge a wide range of reactive oxygen species (ROS). The mechanisms involved in the antioxidant capacity of polyphenols include suppression of ROS formation by inhibition of enzymes involved in their production such as oxidases which include lipoxygenase (LO), cyclooxygenase (CO), myeloperoxidase (MPO), NADPH oxidase, and xanthine oxidase (XO) [47]. Moreover, they have also been known to inhibit enzymes indirectly involved in the oxidative process, such as phospholipase A2. On the other hand, polyphenols induce antioxidant enzymes such as glutathione peroxidase (GPx), catalase, and superoxidase dismutase (SOD) that decompose hydroperoxides, hydrogen peroxide, and superoxide anions, and inhibit the expression of enzymes such as xanthine oxidase [45].

Antioxidant Activity of Jujube Fruit

Different methods were used to evaluate antioxidant capacity mainly 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity and reducing power assay [42]. However, many studies showed that different jujube cultivars possess varying potential antioxidant activity [11,29, 40, 48]. For example, in a study done by Li *et al.* [42] the antioxidant capacity of extracts from five cultivars of Chinese jujube were evaluated. The data showed that the antioxidant activity of extracts decreased in the order of *Zizyphus jujuba cv. jinsixiaozao*, *Zizyphus jujuba cv. yazao*, *Zizyphus jujuba cv. jianzao*, *Zizyphus jujuba cv. junzao*, *Zizyphus jujuba cv. sanbianhong*. The extracts of jujube cultivars such as *Zizyphus jujuba cv. jinsixiaozao*, *Zizyphus jujuba cv. yazao* and *Zizyphus jujuba cv. jianzao* showed higher antioxidant activity than α -tocopherol.

It was shown in another study that Jujube peel had the highest antioxidant capacity, which was reflected by the highest content of total phenolics, flavonoids, and anthocyanins that are found in the peel part. Also, the predominant phenolic acid in jujube peel was protocatechuic acid, followed by gallic acid, chlorogenic acid, and caffeic acid. The study indicated that Chinese jujube has a significant potential to use as a natural antioxidant [17]. Recently Lin *et al.* [11] studied the effects of different fruit parts and extraction conditions on the antioxidant properties of jujube (*Zizyphus jujuba*

Mill). The results revealed that jujube peel with pulp exhibited better antioxidant capacity than did 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 (2,20-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging ability, total flavonoids content and reducing power.

Moreover, Koley *et al.* [49] reported that Indian jujube is a good source of ascorbic acid and total phenolics that ranged from 19.54 to 99.49 mg/100 g and 172 to 328.6 mg GAE/100 g, respectively. The FRAP (ferric reducing antioxidant power) and CUPRAC (cupric reducing antioxidant capacity) of Indian jujube were ranged from 7.41 to 13.93 and 8.01 to 15.13 $\mu\text{mol Trolox/g}$, respectively.

In addition, the antioxidant activity of polysaccharides from jujube fruit has been demonstrated by many studies. In a study conducted by Li *et al.* [48], the antioxidant activity of the four water-soluble polysaccharide fractions (ZSP1b, ZSP2, ZSP3c, and ZSP4b) of the jujube fruit was determined, and it was suggested that ZSP3c and ZSP4b, containing more uronic acid, had stronger free radical scavenging activities than ZSP1b, containing no uronic acid. Whereas, another study that compare the antioxidant activity of three polysaccharides from jujube fruit showed that the polysaccharide with higher galacturonic acid content has better antioxidant bioactivities [50].

Based on previous studies, it can be concluded that jujube fruit has potential antioxidant activity and can be applied as a natural antioxidant ingredient in foods and pharmaceuticals.

Effect of Polyphenols on Inflammation

Anti-inflammatory activities of the polyphenols such as quercetin, rutin, morin, hesperetin, and hesperidin have been reported in acute and chronic inflammation in animal models. Rutin is only effective in the chronic inflammatory processes especially in arthritis; and flavanones are also effective in neurogenic inflammation induced by xylene [51]. Quercetin has been reported to reduce paw edema induced by carrageenan [52]. Polyphenols may affect enzymatic and signaling systems which are involved in the inflammatory processes, such as tyrosine and serine-threonine protein kinases. These enzymes are known to be involved in cell activation processes such as T

cell proliferation, B lymphocyte activation [53], or cytokine production by stimulated monocytes. Genistein has been reported as a specific inhibitor for tyrosine-protein kinase [54]. This latter compound may be involved in some anti-inflammatory effects since T cell proliferation is accompanied by phosphorylation of tyrosine of particular proteins.

In addition, various investigations have shown that different polyphenols modulate the activity of arachidonic acid metabolizing enzymes such as cyclooxygenase (COX), lipoxygenase (LOX), and NOS. Inhibition of these enzymes reduces the production of AA, prostaglandins, leukotrienes, and NO which are among the key mediators of inflammation [55].

Anti-Inflammation Property of Jujube Fruit

Inflammation is a physiological response of a body to stimuli, including infections and tissue injury. It is caused by the release of pro-inflammatory mediators like nitric oxide (NO) and prostaglandin (PGs) through induction of inducible nitric oxide synthase (iNOS) and cyclooxygenase [56,57]. These further mediate the initiation, progression and persistence of acute and chronic inflammatory pathological conditions [58]. Besides, activated macrophages may also lead to the secretion of cytokines, such as tumor necrosis factor – α (TNF- α) and Interleukin-6 (IL-6) [59].

High levels of inflammatory cytokines and reactive oxygen species are proposed to contribute to the pathophysiological mechanisms associated with various inflammatory disorders. So the control of inflammation is very important for improving health since inflammation can aggravate arthritis, diabetes, and other diseases [60].

Many studies showed the therapeutic potential of *Z. jujuba* in the treatment of various inflammatory conditions. For example, Al-Reza *et al.* [61] confirmed that the essential oil from seeds of *Z. jujuba* has been reported to prevent an inflammatory reaction in the skin. The anti-inflammatory action of jujube was also described by [19]. Their study showed that the triterpene acids fraction was the most active part of jujube through the inhibitory effects on the inflammatory cells. Goyal *et al.* [41] suggested that *Z. jujuba* fruits play a protective role against experimental acute and chronic inflammatory reactions in rats, by reducing NOS activity. This effect may be due to the presence of glycosides, flavonoids and terpenes. The results of another study demonstrated that the ethanolic extract

of *Z. jujuba* was able to inhibit carrageenan-induced paw oedema in rats to a significant degree [62]. Recently, polysaccharides from *Z. jujuba* fruit were also reported to exert good anti-inflammatory activity through decreasing levels of inflammatory cytokines such as TNF- α , COX-2 and IL-17 and by suppressing nitric oxide production [37].

CONCLUSION

Jujube fruit is a dietary supplement with high contents of bioactive compounds such as dietary fibers, minerals, and natural antioxidant compounds. Based on the previous studies, jujube fruit can possess good antioxidant and anti-inflammatory activity rendering it a functional food. Since jujube fruit has diverse biological activities, further biological studies including clinical-based studies are recommended to explore the health - promoting effect of jujube.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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